Arnold Schwarzenegger
Governor

Statewide Small Hydropower Resource Assessment

PIER FINAL PROJECT REPORT

Prepared For:
California Energy Commission
Public Interest Energy Research Program

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ABSTRACT

Senate Bill 1078 [SB 1078, Sher 2002] restricted eligibility of small hydroelectric facilities under the Renewables Portfolio Standard (RPS) program to those that do not require "… a new or increased appropriation or diversion of water …" RPS-eligibility will likely be the primary driver of small hydropower development in California for the foreseeable future because of access to Supplemental Energy Payments that make projects more economic. Given the SB 1078 restrictions, small hydropower in man-made conduits is the sector that likely offers greatest RPS-eligible potential. This study indicates that approximately 255 megawatts of RPS-eligible small hydropower potential could be developed in man-made conduits with current technologies.

Small hydropower development faces significant challenges. Although environmental permitting issues are less difficult for facilities sited in existing man-made conduits, large capital costs often make these projects uneconomic. In addition, the risks and complexities of selling the small hydropower output into bulk power markets often render such projects too risky and/or uneconomic, particularly since the owners of these systems are usually water agencies and irrigation districts that have other priorities.

Changes to current regulatory rules are needed to remove barriers to development of small hydropower in man-made conduits. Research and development should also continue into low-head technologies, particularly those that make projects more cost-effective by reducing or eliminating need for costly civil works. Meanwhile, the 2005 Energy Policy Act (EPAct) provides timely new incentives for both incremental and new hydropower development that could be accessed to accelerate development of additional hydropower capacity in California.

The California Energy Commission's 2005 Integrated Energy Policy Report (IEPR) to the Governor and to the Legislature identifies in-conduit hydropower as an important means by which the water sector can attain energy self-sufficiency and reduce impacts on the state's stressed energy resources and infrastructure. PIER has an important role in attaining the IEPR's goal of increasing energy production from water.

Keywords

California hydropower, small hydropower, resource assessment, conduit hydropower

PREFACE

The Public Interest Energy Research (PIER) Program supports public interest energy research and development that will help improve the quality of life in California by bringing environmentally safe, affordable, and reliable energy services and products to the marketplace.

The PIER Program, managed by the California Energy Commission (Energy Commission), annually awards up to $62 million to conduct the most promising public interest energy research by partnering with Research, Development, and Demonstration (RD&D) organizations, including individuals, businesses, utilities, and public or private research institutions.

PIER funding efforts are focused on the following RD&D program areas:

- Buildings End-Use Energy Efficiency
- Energy-Related Environmental Research
- Energy Systems Integration Environmentally Preferred Advanced Generation
- Industrial/Agricultural/Water End-Use Energy Efficiency
- Renewable Energy Technologies

What follows is the final report for the R&D Office Technical Support Contract: NCI 500-01-008, Work Authorization 31-AB-03 conducted by Navigant Consulting, Inc. The report is entitled "Statewide Small Hydropower Resource Assessment". This project contributes to the Renewable Energy Technologies program.

For more information on the PIER Program, please visit the Energy Commission's Web site www.energy.ca.gov/pier/reports.html or contract the Energy Commission at (916) 654-4628.

EXECUTIVE SUMMARY

California's Renewable Portfolio Standard (RPS) program includes some types of small hydropower. The California Energy Commission (Energy Commission) relied upon California water code to determine the meaning of "eligible [hydropower] renewables" as defined by the RPS. Under these definitions, it appears that the most likely type of RPS-eligible small hydropower is that developed within man-made conduits. The Energy Commission, through the Public Interest Energy Research (PIER) program, requested a study to assess the statewide potential of RPS-eligible small hydropower. For purposes of this study, "man-made conduits" included pipelines, aqueducts, irrigation ditches, and canals. The study concluded that approximately 255 megawatts of small hydropower potential in man-made conduits could be developed with current technologies.

Since there was no "perfect" source of information, and given that the cost of surveying all California water agencies and irrigation districts would have been prohibitive, this study applied a hybrid methodology. The Project Team surveyed 43 large and medium sized water purveyors (water agencies and irrigation districts) that collectively accounted for about 65% of the total annual water entitlements recorded in the state's databases. Potential for other water agencies and irrigation districts was extrapolated from these surveys on the basis of total recorded water entitlements, geography and climate, and type of water purveyor (municipal or irrigation). While these data are not perfect, this methodology was deemed adequate for the level of estimate requested by PIER. Operational flows were difficult to obtain and would have been difficult to employ for an estimate of this kind, due to their high variability by season and by year as a result of a wide variety of factors, including natural fluctuations in hydrology.

There are several major barriers to development of small hydropower. Capital costs are relatively high compared to larger "conventional" units, due to high (largely fixed) costs of environmental permitting, site development, and interconnection. Operations and maintenance costs are also largely fixed within a certain range. In addition, the location of small hydropower potential is often remote from loads, necessitating lengthy transmission or distribution lines to be constructed to interconnect to the grid. Further, if power produced cannot be used on-site, current regulatory rules provide that it must then be sold into the wholesale bulk power market. The combination of lower prices for power with higher transaction costs and risks is a major deterrent to development of small hydropower.

While hydropower technology is very mature, the search for more efficient technologies continues. Some improved efficiencies can be realized by better optimization of turbine designs and operations, made possible by computerized software and automated functions. Other efficiencies are expected from technological advances that increase the opportunity to capture energy from low

head resources. In addition, continued development of small packaged systems that require little or no civil works for installation significantly improve small hydropower economics.

PIER is well positioned to support development of the state's small hydropower opportunities through continued research and development of new technologies and applications. In addition to encouraging development of packaged units and low head technologies, PIER could demonstrate the viability of non-conventional applications, such as in wastewater treatment facilities and industrial processes that use a lot of water. PIER can also bring assistance to water purveyors who have small hydropower potential, but are too busy managing their water operations to be bothered with what seem to be very small opportunities for significant cost and risk.

The 2005 EPAct provides new incentives for both new and existing hydropower that can make the economics more attractive. An appropriate role for PIER would be to develop technical assistance programs that bring water purveyors and developers together to take advantage of the new federal incentives and accelerate development of California's small hydropower potential in municipal and water irrigation systems.

In its 2005 Integrated Energy Policy Report (IEPR) to the Governor and the Legislature, the Energy Commission specifically identified in-conduit hydropower as an important means by which water and wastewater agencies can reduce the energy intensity of their activities, thereby reducing impacts on the state's stressed energy resources and infrastructure. PIER has a key role in helping to attain the IEPR goals and objectives.

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CHAPTER 1 - INTRODUCTION

1.1 Background and Overview

The California Energy Commission's Public Interest Energy Research (PIER) division engaged Navigant Consulting, Inc. (NCI) to conduct a statewide assessment of California's "RPS-eligible" small[1] hydropower capacity.

"RPS-eligibility" is defined by California legislation SB 1078 California Renewables Portfolio Standard Program, as interpreted and clarified by the Energy Commission in its Renewables Portfolio Standard Eligibility Guidebook (May 2004). Specifically, SB1078 provides that:

> " A new hydroelectric facility is not an eligible renewable energy resource if it will require a new or increased appropriation or diversion of water under Part 2 (commencing with Section 1200) of Division 2 of the Water Code. "

The Energy Commission relied upon California Water Code Sections 1201 and 5100(b) respectively to define the two primary determinants of RPS-eligibility, namely "appropriation" and "diversion". The Energy Commission decided that RPS eligible hydropower must be 30 megawatts or less, and must either be located in-state or satisfy out-of-state requirements. Facilities placed in service prior to September 12, 2002 are only RPS-eligible if they were not owned by an investor-owned utility, nor their generation procured by an investor-owned utility, as of that date. Facilities that either commenced operations or were repowered after September 12, 2002 are eligible only if they do not require a new or increased appropriation or diversion of water.

For purposes of determining eligibility, the terms "appropriation" and "diversion" are deemed to have the same meaning as in California Water Code Sections 1201 and 5100(b), as follows.

> Sec. 1201. Public water of state; appropriation
> All water flowing in any natural channel, excepting so far as it has been or is being applied to useful and beneficial purposes upon, or in so far as it is or may be reasonably needed for useful and beneficial purposes upon lands riparian thereto, or otherwise appropriated, is hereby declared to be public water of the State and subject to appropriation in accordance with the provisions of this code.
> (Stats.1943, c.368, p.1614, Sec. 1201.)
>
> Sec. 5100. Person; diversion

(b) “Diversion” means taking water by gravity or pumping from a surface stream or subterranean stream flowing through a known and definite channel, or other body of surface water, into a canal, pipeline or other conduit, and includes impoundment of water in a reservoir. (Added by Stats.1965, c.1430, p.3358, Sec.1.)

In public hearings, the Energy Commission, staff and members of the public sought to interpret the intent of the legislature with respect to SB 1078’s qualification of “eligible renewable energy resources”. In particular, there was considerable debate over the meaning of “no new or increased appropriation or diversion of water”.

In its May 2004 guidebook, the Energy Commission clarified that the primary determinant of RPS eligibility is not whether a new or revised permit is required, but whether a new or repowered small hydroelectric project can demonstrate that it could operate without a new or increased appropriation or diversion of water.[2]

1.2 Project Objectives

PIER had two primary objectives for this project:

- Assess the magnitude of potential and identify locations of RPS-eligible small hydropower sites in California.
- Estimate capital and operations and maintenance (O&M) costs associated with identified classes of sites.

PIER requested that NCI focus its evaluation on that category of likely RPS-eligible hydropower that (1) had been least studied, and (2) appeared to offer the most potential. Specifically, while a number of studies of hydropower potential in California have been conducted, those studies did not focus on undeveloped hydroelectric generation potential in man-made conduits (e.g., pipelines, aqueducts, irrigation ditches, and canals).

1.3 Report Organization

Phase 1 of this study entailed developing a baseline understanding of California’s potential for RPS-eligible small hydropower by identifying gaps and overlaps in prior work done by others. In Phase 2, the Project Team built upon the baseline to develop an order-of-magnitude estimate of total statewide potential.

This report describes the methodology and data that were used to develop the estimate of statewide RPS-eligible small hydropower potential in man-made conduits. In addition, this report describes some opportunities for increasing the efficiency of existing hydropower facilities, the state of current small hydropower technology, and the drivers of development costs that ultimately determine feasibility. In addition, new incentives for incremental hydropower established by the

2005 Energy Policy Act and their potential impact on small hydropower development in California are described.

CHAPTER 2 - PROJECT APPROACH

This section describes the general approach and methodology applied to this project. Additional details and references can be found in Appendix I of this report.

2.1 Study Parameters

The following parameters were established for this study:

- Estimate RPS-eligible hydropower potential in man-made water conveyance conduits (canals, irrigation ditches, aqueducts, pipelines)
- Total installed capacity at any one site should be no less than 100 kilowatts, and no more than 30 megawatts
- Minimum head 9 feet
- Focus on counties identified by PIER as current or projected (future) transmission congestion zones[3]
- No determination of development feasibility at this time

The threshold of 100 kilowatts was selected as the minimum economic size for a small hydropower opportunity. Nine feet was selected as the minimum developable head for most applications, absent technological change.

2.2 Study Scope

This study focused on estimating the undeveloped hydropower potential within man-made conduits, both open and closed, for California's water agencies and irrigation districts, on the presumption that this sector holds the greatest potential for RPS-eligible small hydropower development.

There are other types of RPS-eligible hydropower opportunities. In fact, any large volume of operational flows, both influent and effluent, could present an RPS-eligible hydroelectric opportunity. Several wastewater treatment agencies have investigated or are now investigating the potential for small hydropower opportunities in their wastewater pumping facilities. In addition, mining and other operations that use large quantities of process water may be candidates.

Other RPS-eligible hydropower opportunities include:

- Increasing hydropower production and capacity at existing facilities without exceeding the 30 megawatt limit

- Increasing the capacity of existing units at any particular site up to 30 megawatts through repowering and/or reoperations[4]

Both of the above opportunities required site or system specific information that were beyond the scope of this study.

Following are the tasks that were performed for this study:

1. Establish RPS-eligible baseline. Prior studies were reviewed to establish the estimated amount of small hydropower potential in California, excluding man-made conduits.

2. Research present state of technology and available equipment choices. Equipment options were matched to various types of applications to determine the "best fit" for purposes of estimating potential output at identified sites.

3. Recommend methodology for estimating RPS-eligible potential. Available data were reviewed to determine the preferred approach to this study.

4. Conduct detailed assessment of small hydropower potential for sampled water agencies and irrigation districts. Selected water purveyors' systems were surveyed to determine small hydropower potential.

5. Estimate statewide potential in terms of total capacity (megawatts). The potential of sampled water agencies and irrigation districts was extrapolated to other water agencies and irrigation districts deemed to have "comparable" characteristics.

6. Estimate coincident peak capacity (megawatts) and total energy production (megawatt hours). Estimates were made of coincident peak capacity, and monthly, seasonal and annual energy production on the basis of expected operations by type of water system (e.g., municipal vs. irrigation).

7. Estimate the estimated cost of capital and operating costs for various types of small hydropower facilities. The levelized cost of energy (LCOE) was computed on a basis comparable with other types of renewable resources and technologies included in the Energy Commission's 2003 Renewable Resource Development Report (RRDR) to facilitate comparison.

2.3 Study Approach

In order to support development of a rational sampling methodology, the Project Team searched for a comprehensive listing of water agencies and districts that included service territory in acres or square miles, miles of canals and/or pipelines, annual water entitlements, annual water deliveries, and any other data that might be helpful in computing undeveloped small hydropower potential. Various sources appeared to hold pieces of the puzzle; but no one source seemed to have a comprehensive listing of California's water purveyors, and certainly not with the critical data desired by entity.

The Project Team therefore assembled a listing of water purveyors from several sources. State water contractors listings were obtained from the California Department of Water Resources, Federal water contractors listings including Colorado River Contractors were obtained from the U.S. Bureau of Reclamation, water rights holders listings were obtained from the State Water Resources Control Board (SWRCB), and well water users were obtained from the “History of AWCA (Association of California Water Agencies)”. While the listing of state and federal water contractors can be expected to be reasonably complete, water rights holders listings are limited to post-1914 rights holders, as pre-1914 rights are not subject to SWRCB jurisdiction. In addition, since reporting of groundwater consumption to ACWA is voluntary, the database is incomplete. Checking the resultant list against membership directories of various water and irrigation associations confirmed that the list includes the largest California water purveyors.

Once a relatively complete listing of water purveyors in the state was compiled, the Project Team needed to conform the various data sources to a consistent basis and fill in gaps. The initial compilation resulted in identification of nearly 1,000 entities with contracts and water rights as small as 3 acre feet per year (less than 2,700 gallons per day). Upon reviewing the universe of types of water rights holders, the Project Team decided to reduce the list to the 250 entitles that hold annual entitlements of 5,000 acre-feet or more. The basis for this decision was that entities with less than this amount of water would be unlikely to have any potential for the minimum study threshold of 100 kilowatts. The inventory of water purveyors was then stratified by quantity of annual water entitlements, as shown in Table 1:

Table 1 Water Purveyors by Size of Annual Water Entitlements

# of Entities	Classification	Size Range
12	Large	500+kAF
93	Medium	50kAF to 499kAF
59	Small	20kAF to 49kAF
86	Very Small	5kAF to 19kAF

kAF = 1,000 acre feet

The listing of the 250 water purveyors that were identified as holding annual entitlements of 5,000 acre feet or more is provided as Appendix II.[5] The study team subsequently decided that very small water purveyors (i.e., holding annual entitlements less than 20,000 acre feet) were also unlikely to meet the minimum threshold of 100 kilowatts. Consequently, the study focused on those water purveyors holding water entitlements of 20,000 acre feet or more (see discussion under Section 2.5).

2.4 Study Methodology

During the course of this study, the approach and methodology were adjusted as needed to account for the following factors.

1. The Study Team's review of prior studies confirmed PIER's hypothesis that the primary gap with respect to RPS-eligible opportunities is omission of a comprehensive study of California's hydropower potential in man-made conduits, which is the focus of this study.

    a. In its April 2004 report entitled "Water Energy Resources of the United States with Emphasis on Low Head/Low Power Resources", the Idaho National Engineering and Environmental Laboratory (INEEL) estimated nationwide small hydropower opportunities. However, INEEL's assessment focused on natural or modified channels (creeks and rivers).

       The 2003 INEEL Study evaluated hydropower potential first by hydrologic region, and then by state, based on natural and modified streams within the U.S. The report considered three technologies: micro turbines, conventional turbines, and unconventional turbines. Micro turbines were classified as generating less than 100 kilowatts, often in low-head applications. Conventional turbines were classified with generation capacities of 100 kilowatts to 30-megawatts. Unconventional technology was described as capacities greater than 100 kilowatts but with head potential less than 8 feet. As this study is targeted to heads greater than 9 feet and generation potentials from 100 kilowatts to 30 megawatts, only the conventional turbine technology as described by the INEEL Study would have been applicable. However, inasmuch as the INEEL Study was based on natural or modified channels (creeks and rivers) the INEEL Study provides little useful data to this study of man-made conduits.

    b. Several studies of small hydropower potential were conducted by the California Department of Water Resources (DWR), the most recent of which was Bulletin 211 published in April 1981. In that study, DWR estimated hydropower potential at 285 man-made sites (dams, pipelines and canals) for 104 water purveyors. The study did not attempt to extrapolate potential to other types of California agencies and districts (e.g., energy and wastewater). In addition, while this study estimates the gross small hydropower potential unconstrained for development feasibility, DWR's Bulletin 211 eliminated consideration of sites that were deemed by the study team to have insufficient head, uneconomic costs, and other significant feasibility challenges. In these respects, the objectives and scope of Bulletin 211 were inconsistent with PIER's objectives for this study.

2. The factors that impact the computation of hydropower potential are different for drinking water agencies and irrigation districts.

a. Irrigation districts are highly seasonal in nature, with irrigation flows varying markedly by season, geography and climate. Drinking water agencies tend to deliver water year round with some seasonal variations in their operations, but to a much lesser degree.

b. Irrigation districts primarily operate via open conduits (canals and ditches). With a higher need to protect water quality, drinking water agencies most often transport water via closed conduits (pipelines).

Thus, the computation of hydropower potential was made separately for drinking water agencies and irrigation districts.

3. The two principal determinants of hydropower potential are head and flow. The initial premise at commencement of this study was that digital elevations could be related to locations of canals and pipelines to compute approximate head for identified man-made conduits. Thereafter, provided that an appropriate GIS representation of flows by region, irrigation system, etc. could be located, those data could be applied to computed head by county to arrive at an order-of-magnitude estimate of hydropower potential for California overall.

   During the course of this study, NCI researched various sources of data to evaluate their suitability for this study. A number of significant issues were encountered.

   a. The canals and pipelines database from the California Spatial Library was compiled from several sources, including aerial photographs that captured surface manmade conduits and some pipelines identified in U.S. Geological Survey (USGS) topographic maps. Many facilities that are not visible and for which information was not readily available (e.g., underground pipelines and conduits) are omitted from this database.

   b. Digital elevation models (DEMs) could be applied to compute head at various points on man-made conduits; however:

      (1) Man-made conduits tend to not follow the natural topography. Therefore, irrigation drops (potential hydropower sites) would not be readily determinable through DEMs.

      (2) Most available DEMs have a precision of 30 meters, which is inconsistent with the study objective of identifying opportunities 9 feet or greater.

   c. While data about historical hydrology by region are available, there is presently no GIS database available to represent operational flows (quantity and/or timing) in man-made conduits.

These data gaps and imperfections led the Project Team to recommend a hybrid methodology that depended on site surveys and phone interviews with 43 water purveyors who collectively account for 65% of annual recorded water entitlements in the state. The estimated potential of these sampled entities was then extrapolated to “like” entities on the bases of primary water system function (irrigation vs. municipal) and geographic region (north, central and south). For purposes of this extrapolation, the 12 largest water agencies with annual water entitlements exceeding 500,000 acre feet were deemed to be unique and not representative of any other water agencies. Consequently, each of the 12 largest water agencies was surveyed, and their potential was not utilized in the extrapolation.

4. While turbine technology has not changed substantially in over 50 years, advances have been made in the areas of conversion efficiency. In addition, current efforts are underway to substantially improve turbine performance at very low (i.e., 9’ to 15’) heads. Natural Resources Canada (NRC) has a sophisticated public domain screening tool for evaluating projected costs and performance of various types of turbines in differing configurations and site specific conditions. The study team applied this model, known as “RETScreen™”[6], to estimate the hydropower potential of identified opportunities.

2.5 Estimation Methodology

The Project Team’s evaluation of available data and general characteristics of the 250 water agencies and districts led to a hybrid methodology, described generally as follows:

- Very large water purveyors were evaluated through site survey or interview. These very large entities are unique, both as to their system design and operations, and are not deemed useful for estimating the potential of other water agencies and districts.

- The remaining population of California water purveyors was segregated by size (in terms of annual water entitlements and geographic boundaries), by type (irrigation districts vs. water agencies, and by geographic region (North, Central, South). Representative agencies and districts were selected from each group (Table 2), and their potential estimated in kilowatts. Assumptions as to water operations patterns for North, Central and South regions dictated the assumed load factors used to compute energy (kilowatt hours).

The approach employed is a non-statistical sampling methodology that relies upon closer inspection to acknowledge the highly variable nature of the study population, both in terms of system design and configuration, and in operations. For purposes of the extrapolation, very small water agencies (annual water entitlements less than 20,000 acre feet) were eliminated on the basis that they were not likely to have sufficient water to meet the minimum study threshold of 100 kilowatts.

Table 2 Water Purveyors Surveyed vs. Estimated

Annual Water Entitlement (kAF)	Group	Count	% Water	Total Water (kAF)	Surveyed		Estimated	
					Count	Water (kAF)	Count	Water (kAF)
>=500	Large	12	49.53%	16,300,456	12	16,300,456	0	0
50 - 499.9	Medium	93	34.57%	11,378,303	29	3,108,343	64	8,269,960
20 - 49.9	Small	59	15.90%	5,230,537	2	2,029,536	57	3,201,001
	Totals	**164**	**100.00%**	**32,909,296**	**43**	**21,438,335**	**121**	**11,470,961**

<u>Note</u>: Very Small water purveyors with annual water entitlements less than 20,000 acre feet were eliminated from this computation. These 86 entities accounted for an additional 928,740 acre feet, approximately 3% of the total amount of annual water entitlements identified for the 250 largest water agencies.

The characteristics of medium and small water purveyors were not deemed sufficiently different to justify separate computations. Consequently, these entities were combined for purposes of the extrapolation. Table 3 shows the extrapolation factors thus derived for small and medium water purveyors.

Table 3 Estimation Factors Employed

Type	Geog	Total Water	Surveyed	Estimated	FACTOR
I	C	4,875,757	1,096,880	3,778,877	4.44511
I	N	3,913,071	801,988	3,111,083	4.87921
I	S	2,856,975	1,429,475	1,427,500	1.99862
M	C	954,792	252,500	702,292	3.78135
M	N	1,957,976	828,236	1,129,740	2.36403
M	S	2,050,269	728,800	1,321,469	2.81321
TOTALS		**16,608,840**	**5,137,879**	**11,470,961**	**3.23263**

Note: Type = “I” (Irrigation) or “M” (Municipal)
Geographic Location = “C” (Central), “N” (North) or “S” (South)

The above factors were then applied to the medium and small sized water agencies by type and geographic location, and then added to findings from large water agencies with similar characteristics.

GIS remained an essential component of this hybrid methodology, in that the potential of the studied entities was extrapolated to the represented population by number of miles of canals and/or pipelines recorded in the California Spatial Library for “like” entities. Canals, pipelines and dams attributes identified through survey or interview were captured wherever possible to update the California Spatial Library. Canal layer findings were supplemented with individual purveyor GIS data when available.

The output from this study was integrated into PIER’s “Strategic Value Analysis” (SVA) GIS database that relates the energy potential of a wide variety of renewable resources to key electric system criteria, such as transmission congestion and shortages of local energy supplies. Recognizing that concerns about infrastructure security would likely prohibit obtaining detailed information about water systems and the locations of specific facilities, PIER decided that an estimate of the potential by County would suffice for purposes of this study. However, site specific data was provided for incorporation into PIER’s GIS database wherever possible, but in a manner that did not allow ready identification of the specific project site(s).

The load factors utilized to compute monthly energy production were based first on the estimated seasonal flows determined through survey or interview, and then adjusted for likely variability in flows and downtime for maintenance and repair.

- For those entities with distinct summer irrigation patterns, a 6.5 month average irrigation season (April through October) was assumed. Since estimated potential was based on average flow data wherever available, a high monthly capacity factor of 90% was assumed during operating months on the assumption that maintenance and repair would typically occur during fall and winter. This yields an average annual load factor of 45.2%.

- For municipal water systems and 12 month irrigators (e.g., southern region) with year-round flows, a 70% average load factor was assumed during operating months, with one month of scheduled downtime. This yields an average annual load factor of about 64%.

Wherever better information was available as to scheduled flows, these data were used.

CHAPTER 3 - STUDY RESULTS

3.1 Magnitude of Potential RPS-Eligible Small Hydropower

Of 12 large water purveyors[7], 8 were found to have undeveloped small hydropower potential in man-made conduits. The total estimated potential of 75 identified sites was 81,393 kW. Six additional identified sites were excluded from these computations because their potential was less than the 100 kW threshold established for this study. Sites ranged in size from 148 to 6008 kW. Of these, 24 had potential capacity greater than 1000 kW; 51 were less than 1000 kW. The characteristics of large water purveyors are deemed to be unique and not representative of other water purveyors' systems.

Of 31 medium and small water purveyors[8] surveyed, 24 had undeveloped sites that met the 100 kW threshold, with a total estimated potential of 64,212 kW. Of the 53 sites identified, 20 were greater than 1000 kW. Sites ranged in size from 108 to 9806 kW.

Figure 1 illustrates the sizes of sites that were identified. Of 128 sites, approximately 67% (85) were 1,000 kW or less.

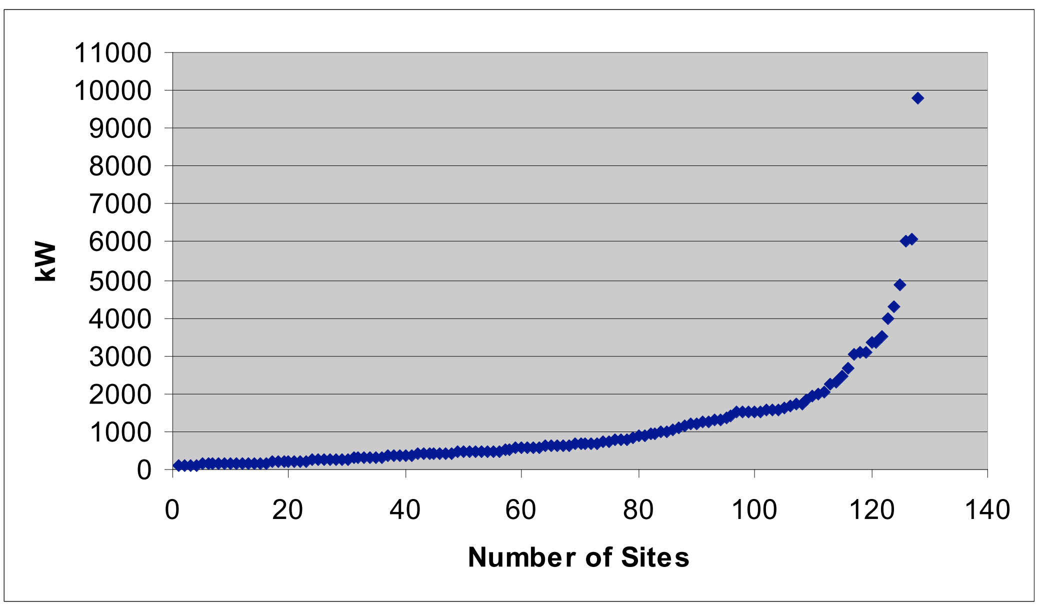


Figure 1 Cumulative Distribution of Identified Small Hydropower Sites by Capacity

A simple extrapolation was used to compute the undeveloped statewide potential of small hydropower in manmade conduits. The estimate was made by extrapolating annual water entitlements for the surveyed population to the population of water agencies and districts that were not surveyed.

Undeveloped potential of small hydropower in man-made conduits is estimated at 255 megawatts, or 230 megawatts on a coincident peak basis (Figure 2). Capacity was split nearly 50/50 between irrigation districts and municipal water systems, at 120 megawatts for irrigation districts and 110 megawatts for municipal water systems.

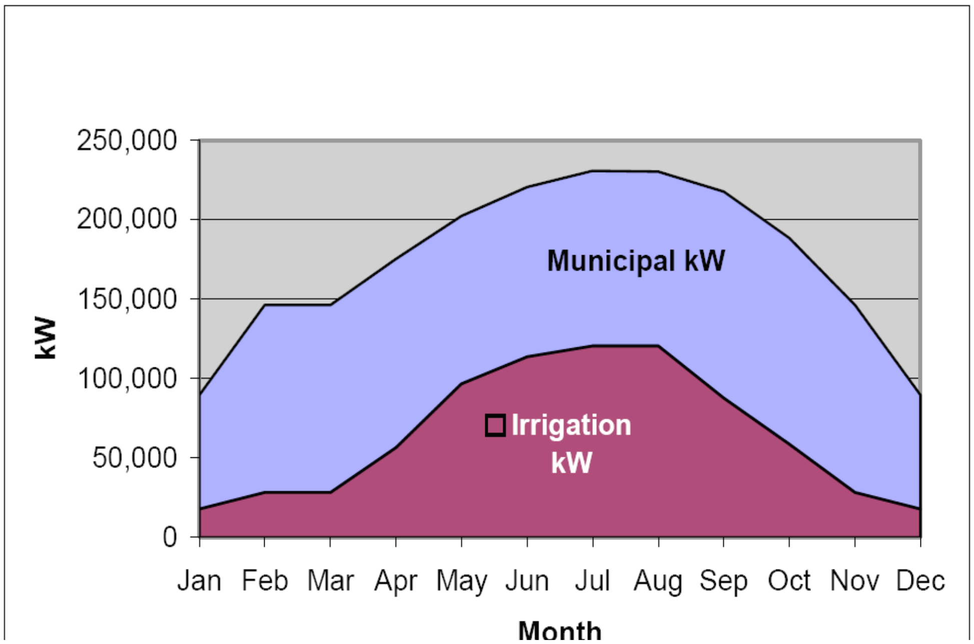


Figure 2 Small Hydropower Potential by Sector

However, energy was much higher for opportunities on municipal water systems which tend to have flow year-round. Irrigation districts, due to their shorter season, have a lower average load factor. On a non-coincident basis, irrigation districts had an average load factor of 47% vs. 55% for municipal water agencies. Figure 3 illustrates the difference in load profiles.

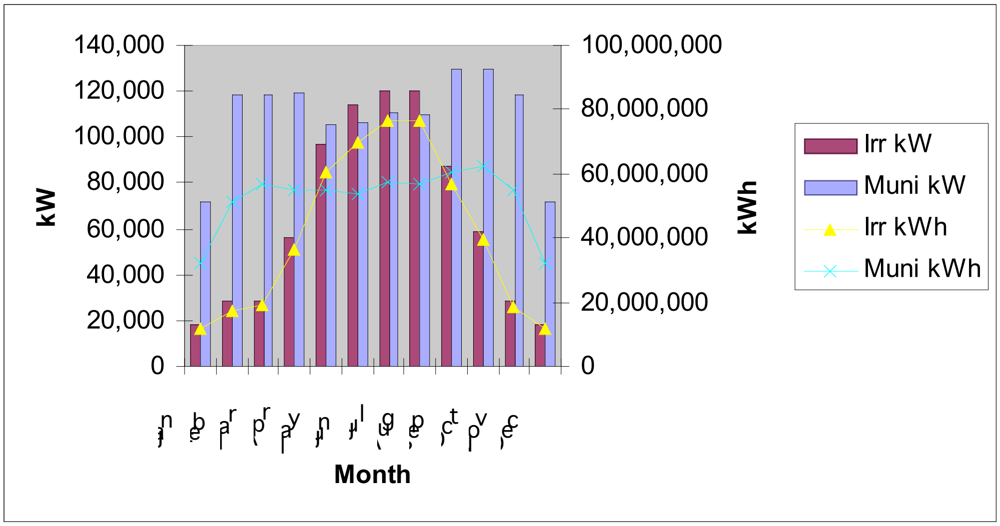


Figure 3 Load Profiles by Sector

Annual energy production from these small hydropower sites is approximately 1122 gigawatt hours. Figure 4 shows undeveloped potential to be highest in the southern region of the state, where there are both heavy year-round irrigation and very large municipal water systems (Los Angeles Department of Water and Power and the Metropolitan Water District of Southern California). Potential is lowest in the central region of the state, where despite many miles of canals, head and flow are not as high. The northern region is characterized by medium to large municipal water systems and foothill water systems that tend to have higher head; and therefore, more opportunity.

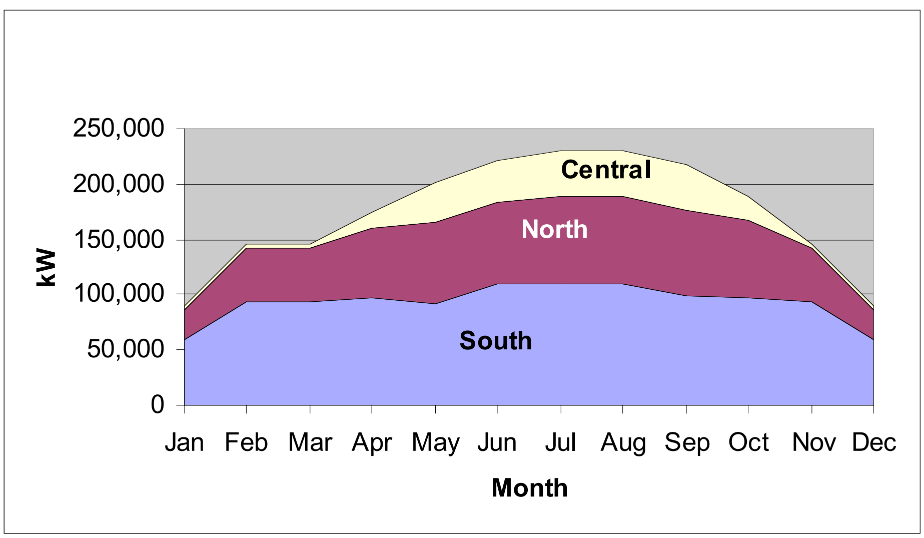


Figure 4 Small Hydropower Potential by Region

These findings were then reconciled with studies performed by the Idaho National Engineering and Environmental Laboratory (INEEL April 2004 “Water Energy Resources of the United States with Emphasis on Low Head/Low Power Resources”) and the California Department of Water Resources’ Bulletin 211 published April 1981 entitled “Small Hydroelectric Potential at Existing Hydraulic Structures in California”. That reconciliation indicates that the total undeveloped small hydropower potential is approximately 2,467 MW, comprised of the following types:

Table 4 Estimated Undeveloped Small Hydropower Potential in California

Type of Resource	Source of Data	Total Est. Potential (MW)*
Man-Made Conduits	ENERGY COMMISSION Study	255
Natural Water Courses	INEEL April 2004	2,189
Dams, Canals & Pipelines	DWR Bulletin 211[9]	23
Total Undeveloped Small Hydropower Potential		**2,467**

*Non-coincident peak

Table 4 appears to indicate that the greatest potential for small hydropower development lies not in man-made conduits, but in natural waterways. After reconciling the results of this study with DWR’s Bulletin 211, the total potential for small hydropower in man-made conduits is approximately 278 megawatts. This number is 12.6% of the potential estimated by INEEL for natural waterways.

Note, however, that none of the above numbers have been qualified for realistic development potential. The objective of both INEEL’s study and this study was to estimate the technical and resource potential for small hydropower, unconstrained for feasibility. As noted in section 3.5 Barriers and Hurdles to Development of In-Conduit Hydropower, there are many reasons why small hydropower may not be developed. The barriers and hurdles to developing hydropower in natural waterways are even more significant than they are for man-made conduits.

The study team estimates that the developable potential in man-made conduits may be 50-60% of the total of 255 megawatts identified. The developable potential in natural waterways is probably much less. Depending on site specific characteristics, the feasibility of successful development may be as little as 5%. Siting and permitting in natural waterways is a costly multi-year challenge, with no assurances of success.

When considered in this context, the potential to develop small hydropower in man-made conduits is more promising. Because of the vastly different environmental impacts and permitting requirements, it is much more likely that 50% or more of the potential in man-made conduits will be developed than any portion of the potential in natural waterways.

As discussed previously, certain types of other RPS-eligible small hydropower facilities are not reflected in the above numbers. For example:

- Incremental RPS-eligible hydropower potential at existing dams, or attainable by repowering and/or reoperations[10], and
- Hydropower potential from industrial processes such as mining, manufacturing, food processing and wastewater treatment

were outside the scope of this study. This study also did not include facilities owned by very large interstate and interbasin systems (the State Water Project, the Central Valley Project and the Colorado River Aqueduct). In addition, facilities owned by the three large investor-owned utilities (Pacific Gas and Electric, Southern California Edison and San Diego Gas and Electric) were not included; nor were those owned by wastewater treatment agencies.

3.2 The Current State of Hydropower Technology

Hydro is a mature technology and industry. Turbines, as a means of harnessing the power of flowing water, have been used for centuries. The earliest known application of turbines for electrical generation occurred in 1880 when the Grand Rapids Electric Light and Power Company generated electricity by dynamo operated by belt from a water turbine. By 1882 the first hydroelectric plant located on Wisconsin's Fox River was in operation. In 1937 the first federal dam was put into operations at Bonneville on the Columbia River between Oregon and Washington. Over the years, turbine technology has improved. Today, many turbines operate at efficiencies, depending on specific applications, in ranges upwards of 92 percent.

Although the applications being investigated for this study are outside the environment of fish species (irrigation canal and pipelines and municipal pipelines), work done by the U.S. Department of Energy[11] shows that modern turbine design can be improved to further increase efficiencies while reducing the mortality of fish that pass through turbines.

While the efficiency of turbines is a linear function,[12] any efficiency increase coupled with increased environmental sensitivity is beneficial.

Small hydro has some of the best operating characteristics of renewable technologies. Beneficial characteristics include predictable dispatch of generation, voltage and VAR[13] control for grid support on synchronous machines, relatively high reliability and availability, and long-term value and life of installed equipment and infrastructure.

3.2.1 Design and Cost Improvements

The overall cost of small hydropower development has remained about the same or has increased only slightly compared to inflationary indexes over the past few decades. There are several reasons for this.

1. ***Improved tools***, such as technical and economic screening programs and design tools, have reduced development costs and risks. In addition, enhanced tools such as computerized flow dynamic software that simulate performance have resulted in more efficient turbine designs and improved overall plant performance.[14]

2. ***Packaged plants*** reduce costs of design and installation. Manufacturers now supply several different sizes and configurations of "standard" turbine generator sets. Most major suppliers will also provide all the mechanical and electrical equipment as a package for "Water to Wire", further reducing design and supply costs. Some new unit configurations require little or no custom civil support structures. For example, some units are now designed to be installed into or in front of existing hydraulic drop structures. Some ultra low head turbines that utilize only the available current at a site have no support structures at all, and are only anchored to their relative location. This "no powerhouse" concept allows for mass-production of multiple small turbines or generating arrays that can further reduce total installed costs.[15]

3. ***Integration of support technologies***, such as Programmable Logic Controllers (PLC), annunciators, and governors designed with off-the-shelf products have reduced equipment space requirements and operating costs while increasing functionality. PLCs can now control, monitor, and provide alarms for all functions of a small hydro facility using a single device. Most water agencies have personnel that can readily program and make control changes to these standard PLCs. Standardized PLC programming reduces training costs and results in improved plant availability. Most new controls equipment now use Windows based software for streamlined integration into existing controls and monitoring systems.

4. ***Standardized communications protocols*** now allow for easy integration of unit monitoring into existing Supervisory Control and Data Acquisition (SCADA) systems. In addition, most electronic governor packages now use standardized components and designs which reduce first costs and maintenance costs, increase availability, enable quicker turnaround on spares, reduce training costs, and significantly simplify changes to control parameters. In addition, remote controls via internet are adding another dimension of sophistication to equipment controls. Some small hydro operators now monitor and control some units solely via the Internet. In addition, cell phones and PDAs can now remotely monitor units.

5. ***Standardized generator exciters*** are now designed to match the required output of standard generators. In the area of small turbine generators, there is increased use of induction type generators (vs. synchronous units). The use of induction "motors as generators" is becoming more popular for installations up to 1000 kW. Use of motors and generators is very cost efficient, since excitation and governor equipment are not needed.

6. ***Improved electronic monitoring packages*** increase the ability to employ predictive maintenance through computer based monitoring and trending. Monitoring devices for the operation of plant are now a fraction of costs 20 years ago. Low cost monitoring and remote sensors have further increased the reliability and availability of small hydro plants. Small hydro plant instrumentation now typically includes site security, vibration, temperature, flow, pressures, levels, and alarms.[16]

The hydro industry has learned from its successes and failures over many years. A multitude of design guides, manuals, and publications on small hydro development leverage the learning from these experiences. Extensive information can be obtained through government and industry resources. The Internet and rapid indexing of reference material have greatly simplified access to relevant information on small hydropower and its development.

3.2.2 Current Research Activities

Most current research involving small hydropower is for in-stream, wave or tidal applications; and most small turbine development is being conducted overseas. Japan, for example, has significant potential for low head applications with an output of less than 100 kW, and is developing pilot projects to explore water and wastewater applications using very small in-line turbine generators. In Europe, efforts are heavily focused on developing the potential of wave and tidal power.

In the U.S., applied small hydropower research is being led by a few equipment manufacturers, with the participation of both public and private stakeholders. Several new technologies are being developed to fill market niches, particularly for ultra low head, tidal, and wave energy applications. Development of ultra low head sites has been spurred by renewed interest in government to promote and increase the use of renewable energy. Further, high interest continues in development of sites that have little or no environmental impact and that do not require new diversions or impoundments of water from natural sources. Below are some examples of small hydropower research and development in the U.S.

- Energetech America is developing a new "wave energy" pilot facility to convert ocean waves into clean energy. A non-profit entity, ***GreenWave Rhode Island (GreenWave),*** was formed for the purpose of developing the proposed facility with funding support from three state renewable energy programs: Rhode Island, Connecticut and Massachusetts. While similar projects are operating or under development in other countries, GreenWave will be the first of its kind in the U.S.[17]

- In December 2002 and January 2003, Verdant Power successfully deployed a prototype turbine system in the East River in New York City. Project participants included the New York State Energy Research and Development Authority (NYSERDA), New York Power Authority (NYPA), Columbia University, the Department of Energy's Idaho National Engineering and Environmental Laboratory (DOE INEEL) as well as the Oak Ridge National Laboratory (DOE ORNL), the Electric Power Research Institute (EPRI), the Hudson Valley Technology Development Center, the U.S. Navy's David Taylor Model Basin, and the National Hydropower Association (NHA). The next step in the project is to install and operate a field of six turbines for 18 months. When installed, this system will be the first grid-connected, distributed generation, multi-turbine array in the world. The project's ultimate goal is to construct a 5 to 10 megawatt power field, comprised of several hundred turbine units.[18]

In addition to the above, some entities are exploring means to replace pressure reducing valves on water systems with hydropower generation. Further, efforts continue to develop packaged systems that require little or no civil works.

Considerable research and testing is currently being performed on ultra low head turbines for tidal areas and fast flowing channels in which infrastructure is minimal. Several promising technologies are being tested. Most work in this area is with the installation and site testing of very small units to determine if their application can be applied to multiple units and in larger sizes. Several sites have been identified with relatively high velocity current or tidal flows that could be future hosts of larger hydro generating "turbine farms", much like large wind farms. Potential sites near population centers such as San Francisco (Golden Gate) and New York City (Hudson River) show promise. Currently, there are no large-scale commercial ultra low head plants in operation in the U.S.

Other R+D efforts are in progress on reaction type turbines that use entirely different impeller designs. Much like the pumps used at fish hatcheries to move stock, these new designs can pass fish through the turbine with minimal harm or injury.

Another promising technology is a new use of small pumps as turbine units. Unregulated pumps coupled with variable speed turbine generators can be used at sites with a wide range of heads and flows. Commercially available pumps cost a fraction of the expense of a regulating turbine with the same maximum flow. When using a pump as a turbine, the flow though the units is not easily regulated. Some installations use multiple pumps or throttle the discharge of the pumps to regulate the required plant flow. With increasingly lower costs of inverter technology, the turbine (pump) speed and its resultant discharge can be regulated to optimize the required flow and head conditions at minimal costs.

3.3 Equipment Options

Hydro developers and suppliers have an extensive list of equipment options and plant configurations to cover almost any site condition. There are plant and equipment options that can provide the best economic designs for most potential sites. Large equipment suppliers and manufacturers have applied their considerable experience to improve large turbine-generators and related equipment, scaling down technologies used on larger units for use in smaller package units.

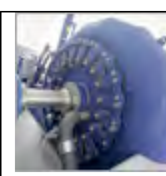
There are two primary types of turbines[19]:

- ***Impulse*** - The impulse turbine generally uses the velocity of the water to move the runner and discharges to atmospheric pressure. The water stream hits each bucket on the runner. There is no suction on the down side of the turbine, and the water flows out the bottom of the turbine housing after hitting the runner. An impulse turbine is generally suitable for high head, low flow applications.

- ***Reaction*** - A reaction turbine develops power from the combined action of pressure and moving water. The runner is placed directly in the water stream flowing over the blades rather than striking each blade individually. Reaction turbines are generally used for sites with lower head and higher flows than impulse turbines.

A description of the types of turbines in use today are described in the following table (Table 5) that was developed from information on the U.S. Department of Energy's website.

Table 5 Types of Turbines

Type of Turbine	Turbine Models & Characteristics
Impulse	*Pelton* - **A pelton wheel has one or more free jets discharging water into an aerated space and impinging on the buckets of a runner. Draft tubes are not required for impulse turbine since the runner must be located above the maximum tailwater to permit operation at atmospheric pressure.**  Pelton Wheel
	Turgo **- A Turgo Wheel is a variation on the Pelton and is made exclusively by Gilkes in England. The Turgo runner is a cast wheel whose shape generally resembles a fan blade that is closed on the outer edges. The water stream is applied on one side, goes across the blades and exits on the other side.**
	Cross-flow **- A cross-flow turbine is drum-shaped and uses an elongated, rectangular-section nozzle directed against curved vanes on a cylindrically shaped runner. It resembles a "squirrel cage" blower. The cross-flow turbine allows the water to flow through the blades twice. The first pass is when the water flows from the outside of the blades to the inside; the second pass is from the inside back out. A guide vane at the entrance to the turbine directs the flow to a limited portion of the runner. The cross-flow was developed to accommodate larger water flows and lower heads than the Pelton.**
Reaction	 Propeller Turbine ***Propeller* -** A propeller turbine generally has a runner with three to six blades in which the water contacts all of the blades constantly. Picture a boat propeller running in a pipe. Through the pipe, the pressure is constant; if it isn't, the runner would be out of balance. The pitch of the blades may be fixed or adjustable. The major components besides the runner are a scroll case, wicket gates, and a draft tube.
	There are several different types of propeller turbines: ***Bulb turbine*** - The turbine and generator are a sealed unit placed directly in the water stream. ***Straflo*** - The generator is attached directly to the perimeter of the turbine. ***Tube turbine***- The penstock bends just before or after the runner, allowing a straight line connection to the generator  Bulb Turbine
	 Kaplan Turbine *Kaplan* **- Both the blades and the wicket gates are adjustable, allowing for a wider range of operation.** *Francis* **- A Francis turbine has a runner with fixed buckets (vanes), usually nine or more. Water is introduced just above the runner and all around it and then falls through, causing it to spin. Besides the runner, the other major components are the scroll case, wicket gates, and draft tube.**  Francis Turbine
	Kinetic - Kinetic energy turbines, also called "free-flow turbines", generate electricity from the kinetic energy present in flowing water rather than the potential energy from the head. The systems may operate in rivers, man-made channels, tidal waters, or ocean currents. Kinetic systems utilize the water stream's natural pathway. They do not require the diversion of water through manmade channels, riverbeds, or pipes, although they might have applications in such conduits. Kinetic systems do not require large civil works; however, they can use existing structures such as bridges, tailraces and channels.

Hydropower costs and configurations vary widely, depending on head, flow and site specific characteristics. For purposes of this analysis, four ranges of head and flows were identified and matched to "best fit" technology options. Since the focus of this study is on small hydropower facilities in man-made conduits, upper and lower ranges of head and flow were developed for 100 and 1000 kW plants. In addition, a third configuration based on potential sites of the sizes and types identified through this study was developed for each range of head.

Table 6 indicates the ranges of head and flow that were used to compute estimated system costs.

Table 6 Turbine Options by Size and Application

Head Range	kW	Head (ft)	cfs	Turbine Effic %	Potential Technologies	Best Fit Technology(s)
Very Low	101	7	286	68.3%	Propeller, Crossflow, Kaplan	Propeller, Kaplan
	1478	13	1800	85.2%		
	1002	19	805	88.3%		
Low	100	20	55	86.5%	Propeller, Crossflow, Kaplan, (possibly) Francis	Propeller, Kaplan
	1068	32	500	91.1%		
	1003	44	335	91.7%		
Medium	102	45	46	70.8%	Crossflow, Kaplan, Francis, (possibly) Turgo	Francis
	1066	72	250	84.3%		
	1004	100	162	87.6%		
High	100	100+	10	84.9%	Crossflow, Francis, Turgo; and possibly Impulse & Pelton	Francis/Impulse
	308	101	50	86.4%		
	1004	101	161	87.7%		

The bases for these assumptions are described below.

Head Range - Although the study parameters established a minimum head of nine feet or greater, many irrigation districts in California have lower head ranges with sufficient flows to meet the minimum 100 kW threshold for this study. Flow and head have inverse relationships with respect to hydropower potential. Specifically, as head increases, less flow is required to produce the same amount of power.

Plant Capacities & Flow Assumptions - Plant capacities were selected on the basis of the head and flows necessary to produce 100 kW, 1000 kW, and an assumed representative flow example in each flow range. Turbine efficiencies reported are from the best-fit selection using the RETScreen^{TM} model. The results of these calculations are expressed in kilowatts (kW) of plant output.

Potential & Best Fit Technology Options - In making the determination as to "best fit" technologies, the Project Team relied upon a tool developed by Natural Resources Canada (NRC) which estimates potential generation given five different types of turbines -- Crossflow, Kaplan, Francis, Turgo and Pelton – in a variety of configurations. The tool, known as “RETScreen^{TM}”, evaluates the efficiency of various turbine designs and the estimated capital cost of each based on site-specific parameters.

Figure 5, courtesy of Natural Resources Canada, provides a useful illustration of the optimized operating envelopes for these five turbines. The “optimal” capacity ranges for each turbine is shown as a function of available head and flow.

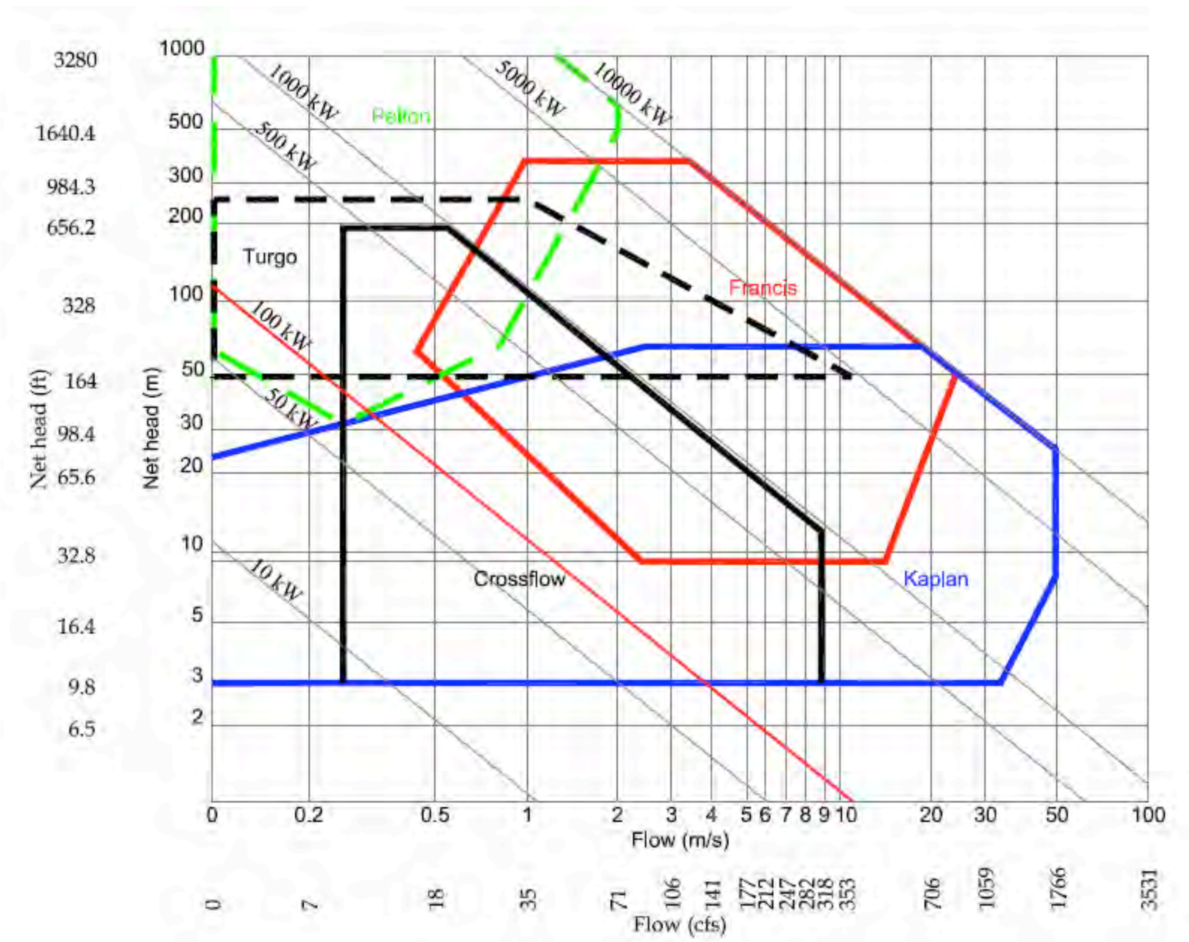


Figure 5 Optimized Turbine Envelopes

[Source: Natural Resources Canada]

The minimum size unit to be considered in this study, 100kW, is noted as a red line traversing from just above 100 meters of head on the left axis to just over 10 cubic meters per second of flow along the lower axis. The range of head and flows for each turbine type show that Francis turbines are all well above the minimum, Turgo and Pelton turbines are mostly above the minimum, approximately one-third of the Crossflow turbine capability falls below the minimum and approximately one-quarter of Kaplan turbine capability falls below minimum.

A review of average efficiency curves for the various turbine types indicates that Pelton and axial flow turbines exhibit broader ranges of efficiencies than do the other general turbine types.[20] The efficiencies exhibited by Kaplan turbines, depending on local installation details, range from 72 percent at 40 percent of flow capacity to almost 93 percent at 100 percent of flow capacity. Below 30 to 40 percent of flow, all turbine technologies lose efficiency rapidly as the percent of flow diminishes. While turbine technologies vary in their efficiencies, this study assumed that generator efficiencies are identical as they are independent of the driver (turbine) efficiency. Given the expected ranges of flow exhibited by irrigation systems and to some degree by municipal water systems, a broad range of higher efficiencies would be advantageous to allow as high a potential generation capacity as possible.

Site investigations are needed before selecting any particular equipment configuration for a specific application.

3.4 Estimated Capital and O+M costs

Once the ranges of head, flow and "best fit" equipment choices were identified, RETScreen™ was used to compute estimated capital costs. Those costs were then adjusted to US$/kW.

Assumptions for the RETScreen™ cost analysis were developed by technical members of the study team on the basis of their professional experience and judgment. The following primary assumptions were employed:

- All facilities will be in place (dams, canals, canal drop structures, pipelines, etc.) and require only minor modification to allow turbine installation (as opposed to construction of all new facilities);
- A transmission line will be no more than 1.0 kilometers long; and will carry 25 KV;
- Interest during construction is calculated at 6.75% (prime 4.25% as of July 2004 plus 2.5%);
- A site feasibility study will cost in the range of 9-11%;
- Land costs will be in the range of 7-9%;
- Engineering costs will be in the range of 10-13%;
- Equipment costs (turbine and related equipment) will be in the range of 35-55%;
- The balance of plant costs will be in the range of 10-40% including civil site development costs.

These values were based on the total calculated kW capability and costs as "water to wire" estimates including generation capacity, total plant efficiency (turbine and generator) and parasitic losses.

Hydropower facility and equipment costs are largely fixed within significant ranges of output. This causes higher head facilities to be much less expensive than low head facilities. For example, a site with 20 feet of head may use the same size turbine and generator as a site with only 10 feet of head. However, the output at the higher head site will be more than double that of the site with 10 feet of head (assuming equivalent flows), Therefore, the amortized capital cost for each unit of output from the facility with 20 feet of head will be about half that of the facility with 10 feet of head.

Hydropower operating and maintenance costs are highly variable, as illustrated in the below diagram (Figure 6) reporting results of a 2002 survey of actual U.S. operating and maintenance cost experience for small hydropower systems. Operating and maintenance costs depend on a variety of factors, including the design and complexity of the facility, site specific hydrology and environmental characteristics, and the remoteness of the site. The frequency of needed monitoring, maintenance and repairs is dependent on these factors. In addition, the level to which remote monitoring and controls can be applied will impact reliability and costs.

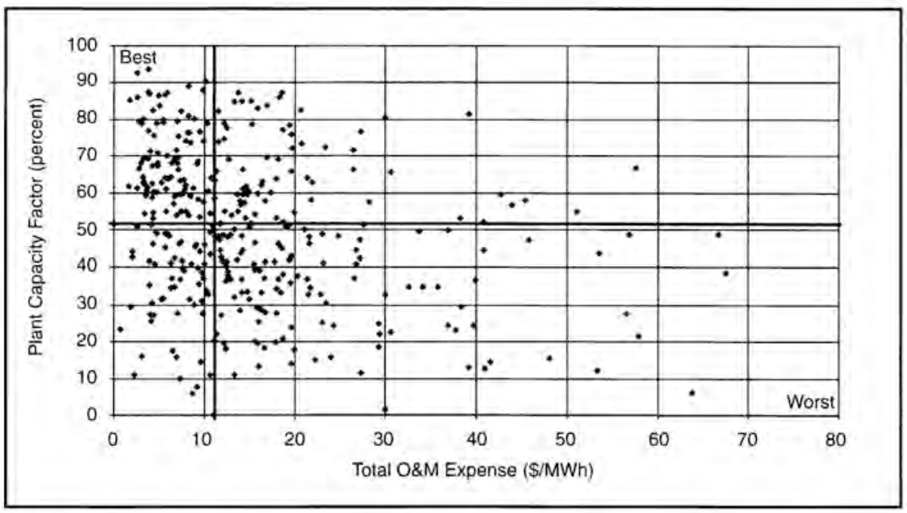


Figure 6 Survey of Hydropower Operating and Maintenance Expenses

Source: Hydro Review, “Using Benchmarking to Assess, Improve Hydro Plant Performance”, October 2002.

Most of the units surveyed in the above study were between 100 and 2,000 kilowatts. The average was approximately $11/MWhr with an average 51% plant capacity factor. Potential small hydropower sites identified through this study indicate expected average annual load factors of 47% (irrigation systems) to 55% (municipal water systems). For purposes of these computations, the average annual load factor of 51.4% indicated in the above benchmarking study was adopted. The industry average of $11.04 per MWH at 51.4% plant capacity factor is used herein, adjusted to 2004 $ of approximately $11.50.

The foregoing assumptions were input to Navigant Consulting's proprietary Levelized Cost of Energy (LCOE) model, applying an effective annual charge rate of 4.84%. The annual charge rate is based on the assumption that the sites identified in this study will be owned and operated by the water purveyors themselves, all of which are public entities. The annual charge is thus based on an assumption of 100% debt financing, 6.75% cost of capital, 25 year debt term, 25 year project economic life, 0.5% insurance (on book value), no income or property taxes, 2% annual inflation rate, and a 51.4% average capacity factor. Inasmuch as hydropower did not qualify for any federal or state tax credits or incentives at the time of this study; and further, since public ownership is assumed, incentives are deemed to be $0.

Using these assumptions, LCOE was estimated for the twelve selected head and flow combinations and was tabulated in Table 7.

Table 7 Levelized Costs of Energy by Size of Hydropower Facility[21]

Head Range	kW	Head (ft)	cfs	Turbine Effic %	Average Load Factor %	Capital Costs $/kW	O&M Costs $/MWhr	LCOE $2004 $/kWhr
Very Low	101	7	286	68.3%	51.4%	$8,574	$11.50	$0.210
	1478	13	1800	85.2%	51.4%	$2,384	$11.50	$0.067
	1002	19	805	88.3%	51.4%	$2,098	$11.50	$0.060
Low	100	20	55	86.5%	51.4%	$3,330	$11.50	$0.089
	1068	32	500	91.1%	51.4%	$1,309	$11.50	$0.042
	1003	44	335	91.7%	51.4%	$1,092	$11.50	$0.037
Medium	102	45	46	70.8%	51.4%	$4,039	$11.50	$0.105
	1066	72	250	84.3%	51.4%	$1,124	$11.50	$0.038
	1004	100	162	87.6%	51.4%	$ 999	$11.50	$0.035
High	100	100+	10	84.9%	51.4%	$2,220	$11.50	$0.063
	308	101	50	86.4%	51.4%	$1,419	$11.50	$0.044
	1004	101	161	87.7%	51.4%	$1,037	$11.50	$0.036

Figure 7 depicts the range of estimated LCOEs in $2004 by head range and flow.

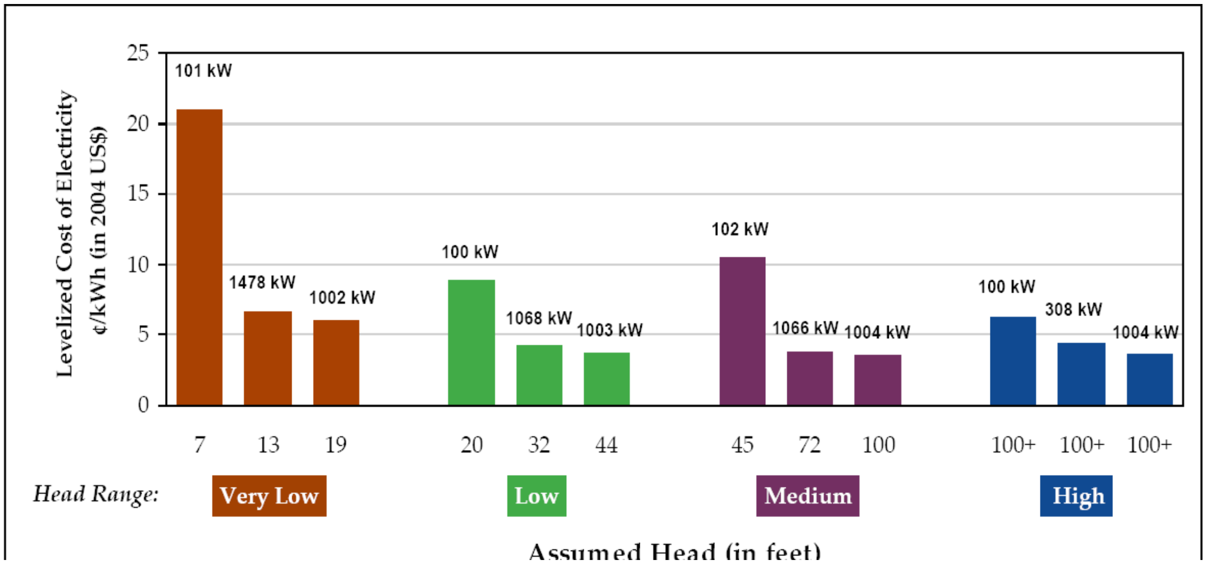


Figure 7 Levelized Cost of Energy (w/o incentives) for Small Hydropower Projects Installed in 2005

Inasmuch as hydropower technology is very mature, there is no basis for projecting significant reductions in capital costs over time. However, as discussed in Section 3.2, "The Current State of Hydropower Technology", modest cost improvements are being realized principally through integration of new, more efficient technologies into overall plant design. Consequently, future LCOEs are deemed to be equivalent to that in $2004 (i.e., modest cost improvements of 2% per annum are deemed to be offset by the 2% per annum escalation factor).

3.5 Barriers and Hurdles to Development of In-Conduit Hydropower

The primary hurdle to development of hydropower continues to be siting and permitting. In the case of in-conduit hydropower, the environmental impacts tend to be low compared to other types of hydropower, significantly simplifying the siting and permitting process. However, several major barriers and hurdles remain:

- ***High fixed costs disproportionately burden small projects, causing the per unit cost of energy to be less economic than larger projects.*** About 77% of the RPS-eligible small hydropower sites identified through this study were under one megawatt in size.[22] Costs of siting and permitting, interconnection, and civil works are largely fixed in nature. These costs would be about the same, whether the hydropower capacity is 100 kilowatts or 1000 kilowatts. Since the fuel (water) is renewable and (virtually) "free", the primary cost of energy produced by hydropower is comprised of amortized capital costs. This creates a circumstance in which small projects are usually not cost competitive with larger hydropower units (although small hydropower generation could be competitive with other types of power that have high fuel costs, such as conventional fossil fuels, or technologies with very high capital costs, such as solar photovoltaics and fuel cells).

- ***Small hydropower sites are often distant from load, further increasing costs of interconnection.*** RPS-eligible small hydropower sites can occur at points along canals and pipelines that are hundreds of miles long, often in remote areas that are distant from loads. This may require miles of transmission or distribution lines to be constructed for interconnection. Very small projects cannot bear these types of costs.

- ***Regulatory rules require that power produced in excess of connected loads be sold into the bulk power market, creating prohibitive power market risks and costs.*** Under existing rules, electric customers can self-provide power, provided that the quantity of power produced does not exceed the amount of the customer's electric use at the point of interconnection. If "excess" power is produced at any point in time, it must either be sold into the bulk power market or the value foregone. The costs and complexities of participating in the wholesale bulk power and transmission markets are daunting for all market participants, but they are prohibitive for very small generators. Net metering rules allow self-produced power to be aggregated over time periods, which helps to alleviate some of these risks. However, small hydropower does not presently qualify for net metering.[23]

The above barriers and hurdles are shared by other distributed generation projects. The smaller the generation facility, the larger the challenge to build an economic project.

The 2005 Integrated Energy Policy Report (IEPR) identified in-conduit hydropower as an important aspect of the state's water-energy relationship and recommended that actions be taken to encourage development of in-conduit hydropower (and other types of environmentally preferred generation).

> "***Recommendation for Increasing Energy Production from Water:***[24]
>
> - The state, in collaboration with water utilities, wastewater districts and stakeholders, should assess and develop a comprehensive policy to promote self-generation, including examining all cost-effective, environmentally preferred in-conduit, biogas and other renewable options for water and wastewater systems.
>
>   Attention should be given to the following:
>
>   - Allowing water and wastewater utilities to self generate and use the produced electricity to offset power requirements at their other locations and for multiple accounts within their own systems.

- Expediting and reducing the cost of interconnection, eliminating economic penalties such as standby charges, and removing size limitations for net metering.
- Evaluating potential incentives to support the development and/or operation of in-conduit hydroelectric facilities."

The above recommendations would alleviate some of the barriers to development of the state's small hydropower potential. However, it will still be challenging to site remote hydropower adjacent to local loads or to points of interconnection.

3.6 Other Types of RPS-Eligible Hydropower

The 2005 IEPR identified another potential class of RPS-eligible hydropower, namely "incremental" or "retrofit" hydropower. Retrofitting existing hydropower facilities with new, more efficient equipment can sometimes increase capacity. To the extent that these retrofits do not result in changed flows, no permits may be needed. If the increase in capacity does not cause an existing facility to exceed the 30 megawatt threshold for "small" hydropower, the increased capacity resulting from such retrofit could be eligible for RPS.

Below are the primary means for achieving efficiency gains and additional capacity through retrofits:

- Reducing friction losses by lining existing tunnels, penstocks and pipelines;
- Replacing turbine runners with new, more efficient designs;
- Improving plant controls (e.g., SCADA and automated generation systems); and
- Improved resource planning and management.

3.7 2005 Energy Policy Act (EPAct)

The recent federal energy bill contains a number of new incentives for new and incremental hydropower production.[25] These include:

- A ten year production tax credit in the amount of 0.9 cents per kilowatt hour for "incremental" hydropower (i.e., new energy at existing hydropower projects through efficiency increases or additions of capacity) and "qualified" hydropower (new hydropower at non-hydropower dams that presently have a FERC license) placed in-service by January 1, 2008.

- Production incentive payments of 1.8 cents per kilowatt hour for development of new hydropower at existing dams or in conduits that are not enlarged or do not require new construction during installation of power generating equipment (subject to maximum incentive payment of $750,000 per facility per calendar year). Eligible units must be placed in service within 10 years.

- One-time capital cost incentives of up to 10% of total costs incurred to increase efficiency of existing hydropower facilities at least 3% or more; maximum payment to any individual project capped at $750,000.

In addition, there are other federal programs that may be beneficial for small hydropower development.

- Federal agencies are required to purchase certain quantities of renewable energy. Incremental hydropower is among eligible renewables.

- Department of Energy is required to conduct a program of research, development, demonstration and commercial application for cost competitive technologies that enable development of new and incremental hydropower, including “fish-friendly” turbines and advanced technologies to enhance environmental performance and yield greater energy efficiencies.

These recent developments are likely to increase small hydropower development in California over the next few years. In addition, other types of hydropower development (e.g., increasing capacity of existing hydropower facilities of any size) may also increase.

Chapter 4 - Conclusions and Recommendations

Small hydropower in man-made conduits offers potential for approximately 255 megawatts[26] of new sources of renewable energy that have significant value, both in terms of helping California meet its Renewable Portfolio Standard (RPS), and in terms of long term energy reliability. However, owners of systems that have small hydropower potential are typically water agencies and irrigation districts whose primary mission is to collect, transport and/or treat water for end users, both urban and agricultural. Development of hydropower in man-made conduits is often deemed a distraction to water purveyors' primary mission. Relatively high capital costs, coupled with the substantial risks of needing to sell output in bulk power markets, often do not justify the development, financial and operating risks.

While the RPS-eligible potential of in-conduit hydropower is modest compared to other renewable sources such as wind and solar, it has some characteristics that make it a high priority for California. In its 2005 Integrated Energy Policy Report (IEPR)[27] to the Governor and the Legislature, the Energy Commission identified development of in-conduit small hydropower by water and wastewater agencies as an important means by which the water sector can attain energy self-sufficiency and reduce impacts on the state's stressed energy resources and infrastructure. The Energy Commission recognized, however, that there were significant barriers and hurdles to develop in-conduit hydropower. Many of these are similar to barriers and hurdles to any type of customer-sited distributed generation. As a result, the Energy Commission recommended modifications to various policies, rules and regulations to alleviate barriers to production of environmentally-preferred renewable and clean energy by water and wastewater agencies. In addition, the Energy Commission recommended that energy efficiency incentives be made available to support development of in-conduit hydropower which essentially represents recovery of energy from water systems.

The Energy Commission conducted stakeholder workshops to develop the findings and recommendations contained in the staff paper that was prepared in support of the 2005 IEPR[28]. Stakeholders recommended various actions intended to increase development of in-conduit hydropower.

1. "***Conduct studies of potential for incremental power production through in-conduit hydropower, pumped storage, and repowering***. In-conduit hydropower is a very attractive option since it produces energy as a by-product of water operations. Pumped storage has unique capabilities to produce power during peak periods. The Hetchy Hetchy example illustrated a potential for increasing the state's hydropower capacity by as much as 10 percent at a fraction of the cost of installing new units and much more quickly."[29]
2. "***Develop cost-effective, environmentally preferred in-conduit, [biogas and other renewable] options for water and wastewater systems***."[30] "Changes in technology may reduce the economic threshold of in-conduit hydropower to less than 100 kW. New packaged systems are being developed that could be dropped

into pipelines and other types of conduits – like canals and aqueducts - without expensive civil works or permitting costs."[31]

3. "***Remove barriers to energy self-sufficiency*** by allowing water and wastewater utilities to self-generate power and provide this power to themselves anywhere on their systems; expedite and reduce costs of interconnections; eliminate economic penalties such as prohibitive standby charges; and remove caps on size of facilities eligible for net metering."[32]

Next Steps

Potential near-term activities should focus on accomplishing the goals and objectives identified in the 2005 IEPR. Specifically, PIER can assist water and wastewater agencies in increasing energy production from water through a variety of activities.

- ***Develop new business models*** that improve economic feasibility of otherwise marginal opportunities through public-private partnerships or other types of business structures that leverage 2005 EPAct tax and other incentives. The scope could include identifying modifications to policies and regulatory rules needed to enable new business models.

- ***Develop demonstration projects*** that illustrate unique applications for in-conduit hydropower such as:
  - » Generating electricity during transport of influent and effluent at a wastewater treatment agency;
  - » Replacing pressure reducing stations with hydropower generation facilities; and
  - » Developing in-conduit hydropower in conjunction with pumped storage facilities.

- ***Conduct technology demonstrations*** that prove the viability and efficiency of different hydropower technologies for specific water or wastewater system applications. For example, determine the "best" in-conduit hydropower technologies for:
  - Large water conveyance systems such as pipelines and aqueducts,
  - Irrigation ditches and canals, and
  - Water and wastewater treatment and distribution systems.

  Each of these applications has distinctly different characteristics that may be more beneficial for one technology option vs. another.

- Identify potential of incorporating in-conduit hydropower into water and wastewater capital improvement programs. The State Water Project and San Francisco's Hetch Hetchy Water and Power Project are investing hundreds of millions of dollars in system upgrades. Other water and wastewater agencies also have large capital programs. PIER can collaborate with these agencies to minimize missed opportunities by influencing decisions to increase the energy production potential of water systems during the capital planning process.

PIER can also help develop the future potential of in-conduit hydropower by investing in technology development. Following are some examples in which technology development is needed.

- Development of packaged units that can be dropped into man-made waterways with minimal custom civil works.

- Very low head systems that can produce power in water and wastewater distribution.

Also, the 2005 IEPR encourages development of all types of "environmentally preferred" energy resources. This could well include wave and tidal technologies.

The ultimate vision is to economically produce power wherever there is flowing water, including the thousands of miles of water and wastewater distribution systems throughout California. Continued research and development is needed to attain that vision.

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[1] "Small" hydropower capacity is defined as 30 megawatts or less. The determination as to whether a facility is considered "small" is made on the basis of total peak hydroelectric generation capacity at any particular site – not the capacity of each generating unit. For example, upgrading an existing 28 megawatt unit by 5 megawatts, whether through increasing the capacity of the existing unit or adding a separate new unit, would cause the facility to lose its designation as "small". Facilities greater than 30 megawatts in total installed capacity are classified as "conventional" hydroelectric facilities.

[2] As examples, ENERGY COMMISSION states "… a small hydro facility that can operate by simply adding hydroelectric power generation as an authorized purpose of use to its existing SWRCB permit or license may be eligible … if this change in use does not require a new appropriation or does not increase the volume or rate of water diverted beyond that which is allowed under that permit or license. Similarly, a water development project that has been granted a permit by the SWRCB but has not been built out and issued a license by the SWRCB may be able to use additional water as authorized under the permit to create electric energy so long as there is no change in water use relative to what the permittee would have used under the approved project." [ENERGY COMMISSION RPS Eligibility Guidebook, May 2004, p.12]

[3] "Hot spots identified by PIER through its "Strategic Value Analysis" Project, see Appendix IV.

[4] "Repowering" is accomplished by changing or upgrading turbines, generators and related hydropower system equipment and other components. "Reoperations" occurs when the operational practices of existing hydropower facilities are modified.

[5] Note that facilities owned by very large interstate and interbasin systems (the State Water Project, the Central Valley Project and the Colorado River Aqueduct) were not included in this study. In addition, facilities owned by power utilities, including the three large investor-owned utilities (Pacific Gas and Electric, Southern California Edison and San Diego Gas and Electric) were not included; nor were wastewater treatment agencies.

[6] RETScreen^{TM} is a registered trademark of Natural Resources Canada. The hydropower estimation tool employed for this study was a module from the RETScreen^{TM} International Clean Energy Project Analysis Software, a unique decision support tool developed with the contribution of numerous experts from Canadian government, industry, and academia. This public domain software was developed to assist in evaluating the energy production, life-cycle costs and greenhouse gas emission reductions for various types of energy efficient and renewable energy technologies ("RETs").

[7] Possessing more than 500,000 AF of annual water entitlements.

[8] Possessing between 20,000 and 500,000 AF of annual water entitlements.

[9] Adjusted for overlaps with this study and for projects that were not in man-made conduits.

[10] See Section 3.7, Other Types of RPS-Eligible Hydropower.

[11] "A Summary of Environmentally Friendly Turbine Design Concepts", Mufeed Odeh, DOE/ID/13741, July 1999.

[12] I.e., a 1% increase in turbine efficiency leads to a 1% increase in turbine output power.

[13] Voltage-ampere-reactive, a measurement of reactive power.

[14] Almost all current plant and equipment design is now computerized, with integrated stress calculations tools and drawings produced with 3-D capability. Integration of 3-D design has significantly improved hydro plant configurations. Previously, these types of problems were only discovered during installation. In addition, turbine generating units are now manufactured and often machined directly from these computerized design programs. The use of computer-aided machine tools reduces production costs. With the use of Computer Aided Design and the Internet, multi-national equipment manufacturers have the ability to almost instantly outsource supply and assembly to the lowest cost production centers and regions. In addition, computerized design and stress analysis has reduced the size and resultant cost of equipment due to better control of the required factors of safety and materials used in their production. Increased use of standardized parts has also resulted in reducing or eliminating need for expensive customized machining of replacement parts.

[15] An example is the current marketing of multiple rack mounted axial flow turbines to be used in non-traditional locations. These small units utilize the local high velocity flows and available head and require a minimum of civil works.

[16] Operating costs can be substantially reduced if a small hydro unit can be safety and reliably operated and controlled remotely. Key to this is the ability for failsafe bypass of water in the event of shutdown. In the past, small plants were often not economic because of the need for daily visits from roaming operators to check and inspect the equipment. Current monitoring and automation control technologies can substantially reduce the need for site visits, significantly enhancing project economics.

[17] http://www.energetech.com.au/index.htm?http://www.energetech.com.au/content/rhode_island.html

[18] http://www.verdantpower.com/initiatives/eastriver.html

[19] U.S. Department of Energy, Energy Efficiency and Renewable Energy (EERE) website : http://eereweb.ee.doe.gov/windandhydro/hydro_turbine_types.html

[20] Axial flow turbines include propeller and Kaplan units.

[21] To facilitate comparison with other renewable energy resources and technologies, the above LCOEs were computed on a basis consistent with that employed in the Energy Commission's "Renewable Resources Development Report" [ENERGY COMMISSION 500-03-080F, November 2003]. Following are the key assumptions employed: Municipal or Co-operative financed projects; 100% debt financed; Discount rate = Weighted Average Cost of Capital = 6.75%; Cost of debt = 6.75%; Inflation rate = 2%; Project economic life = 25 years; Length of loan repayment = 25 years; Federal income tax = 0; State income tax = 0; Insurance = 0.5% of book value, Property tax = 0. Miscellaneous operating expenses = 5% of O&M. Land lease = 0. No incentives (Federal and State) applicable . Annual capacity factor = 35%. After applying escalation, nominal capital and operating costs over the life of the project were discounted back to $2004.

[22] This outcome was anticipated, since most of the economic in-conduit opportunities on large regional conveyance systems have already been developed. See Diagram 1 on p.11.

[23] Section 1251, "NET METERING AND ADDITIONAL STANDARDS" of the 2005 Energy Policy Act amended the 1978 Public Utilities Regulatory Policy Act (PURPA) to require that electric utilities provide net metering service to any electric consumer that the electric utility serves. Under this rule, it appears that any PURPA-eligible renewable resource may hereafter qualify for net metering treatment.

[24] California Energy Commission 2005 Integrated Energy Policy Report [ENERGY COMMISSION CEC-100-2005-007-CMF, November 2005], p.149.

[25] Source: National Hydropower Association.

[26] Approximately 278 megawatts, if DWR's Bulletin 211 is included.

[27] California Energy Commission 2005 Integrated Energy Policy Report [ENERGY COMMISSION CEC-100-2005-007-CMF, November 2005]

[28] "California's Water-Energy Relationship", CEC-700-2005-011-SF, November 2005.

[29] CEC-700-2005-011-SF, op. cit., p.164. "The Hetch Hetchy example" on p.60 stated: "Retrofitting existing hydroelectric facilities, specifically replacing turbine runners and generators with new, more efficient equipment, may increase the capacity of these facilities. To the extent that retrofit does not result in changed flows, no permits may be needed. Hetch Hetchy Water and Power increased the capacity of its system 48 MW by replacing turbine runners and generators with newer, more efficient equipment – at a capital cost of $8 million, less than 17 percent of the cost of installing a new unit of comparable capacity. Since the purpose of these retrofits was to increase the efficiency of hydropower production using the same amount of flows, no permits or approvals were required."

[30] Ibid, p.81.

[31] Ibid, p.55.

[32] Ibid, p.81.

GLOSSARY

ACWA – Association of California Water Agencies

DEM – Digital elevation map

DWR – California Department of Water Resources

GIS – Geographic information system

Head – The vertical distance between the top of the reservoir or water conveyance structure, to the base of the facility at which the turbine is situated.

INEEL – Idaho National Engineering and Environmental Laboratory

kAF – One thousand acre feet

Kilowatt (kW) – One thousand watts

Kilowatt-hour (kWh) – One kilowatt of electricity supplied for one hour

LCOE – Levelized cost of energy

Megawatt (MW) – One thousand kilowatts, or one million watts

Megawatt-hour (MWh) – One thousand kilowatt hours

RPS – Renewable Portfolio Standard, established by SB1078 [Sher 2002]

RRDR – Renewable Resource Development Report

USGS – U.S. Geological Survey

SWRCB – State Water Resources Control Board

Appendices

I-Methodology and Data Development

Below is a description of the methods, primary data and references that were relied upon in preparing this report.

A. Establishment of Baseline Estimate of Small Hydropower Potential

The scope of work required that "baseline" be established from existing literature. A literature search showed that the only relevant studies that had been conducted were by the California Department of Water Resources (DWR) and the Idaho National Engineering and Environmental Laboratory (INEEL). The following studies were evaluated for potential contribution to establishing a baseline estimate.

1. "Small Hydroelectric Potential at Existing Hydraulic Structures in California", Bulletin 211, California Department of Water Resources, 1981.
2. "A Survey of Small Hydroelectric Potential at Existing Sites in California", Bulletin 205, California Department of Water Resources, 1979.
3. "Hydroelectric Energy Potential in California", Bulletin 194, California Department of Water Resources, 1979.
4. "Hydropower Potential of the United States with Emphasis on Low Head/Low Power Resources", Idaho National Engineering and Environmental Laboratory (INEEL), April 2004.

The INEEL study estimated the potential for small hydropower in natural waterways, and thus was not consistent with the scope of this study. DWR's Bulletin 211 identified opportunities in both natural and man-made waterways. As discussed in Section 3.1, Bulletin 211 findings and this study were reconciled in development of Table 4. DWR Bulletins 194 and 205 were replaced by Bulletin 211, and thus were not considered in establishing baseline.

B. Database of California Water Purveyors

The study team sought to identify a comprehensive database of water purveyors, their service territories, and characteristics of their water systems, operations and hydrology. However, no single source was located that provided this type of information for all California water purveyors on a consistent basis. Consequently, a database was assembled from multiple sources.

1. Members of the State Water Contractors (wholesale customers of the State Water Project, owned and operated by the California Department of Water Resources)
   [http://www.publicaffairs.water.ca.gov/swp/contractors.cfm]
2. List of Federal Water Contractors, U.S. Bureau of Reclamation (including Colorado River and Central Valley Project)
3. Database of Water Entitlements, State Water Resources Control Board Division of Water Rights [http://www.waterrights.ca.gov/]
4. Well users, Association of California Water Agencies (ACWA)
   [http://www.acwa.com/aboutacwa/acwamembers/publicagency.asp]

Recorded water entitlements were used as a basis for estimating the small hydropower potential of water purveyors who were not surveyed. The extrapolation estimated potential separately by type of water purveyor (municipal vs. irrigator) and by geographic region (north, central and south). The estimation methodology is described in Section 2.5.

C. Geographical Information System (GIS) Data

GIS was utilized to estimate miles of canals by water agency and by county. Statewide GIS layers were gathered from the California Spatial Library [http://gis.ca.gov/] and imported into ArcGIS, ArcView 8.3. All datasets were projected into Albers NAD27. GIS layers were developed separately for counties, streams and water districts (state, federal and private).

Data was extracted and queried to determine the miles of canals per selected water district and miles of canals per county. Types of hydrography were extrapolated from the original GIS layer to create a hydrography subset of man-made features. The following attributes were captured as identified:

405 – water intake
506 – dam or weir
408 – spillway
409 – gate (flood, tidal, head, check)
414 – ditch or canal
415 – aqueduct
416 – flume
418 – siphon
611 – abandoned or discontinued

To obtain a general estimation of canals within each county, the California canals shapefile was spatially joined to the county shapefile. The resulting shapefile included a summation of canal length in meters per county. Within the attribute table, the canal lengths were converted to miles. Separate shapefiles were then created to compute the miles of canal by water district.

Canal lengths were combined with phone and site surveys to estimate head, flow, and the number of usable drops for canals within each selected district. A specific head of 9 feet or greater and a flow of 120 cfs or greater was necessary to employ a small hydropower facility within an existing canal. Resulting datasets were extrapolated from computations of technical potential of surveyed and interviewed sites to calculate the gross potential for small hydropower in the state, by county and by water district. Calculations were then imported into GIS to provide datasets and GIS data layers that can be utilized in future GIS applications.

All of the GIS data and output was provided to the California Department of Forestry (CDF) that is assisting PIER in developing its "Strategic Value Analysis" GIS system.

D. Potential Hydropower Sites Capacity and Cost

Site surveys of small hydropower potential were conducted by registered professional engineers with direct experience in hydropower development and operations. Head and flow for identified sites were input into a public domain hydropower estimation tool, the RETScreen™ Small Hydro Project Model. The small hydro project model is but one of a suite of tools contained in the RETScreen™ International Clean Energy Project Analysis Software, a unique decision support tool developed with the contribution of numerous experts from Canadian government, industry, and academia. RETScreen™ is a registered trademark of Natural Resources Canada.

The RETScreen™ tool is available at:
http://www.retscreen.net/ang/g_small.php

RETScreen™ is based on Canadian experience and Canadian dollars, but allows for conversion to other currencies. The program cost estimating test results ("Formula" Model) were calibrated to actual experience over 20 years of record for both large and small hydro facilities. Literature provided with the program indicates that the Cost Analysis Model provided will "…provide a baseline, or minimum cost estimate…" for a proposed project. The program suggests that the estimates developed be used for "screening" with a valid range of plus or minus 25 percent. As RETScreen™ uses a national average for U.S. cost estimates, the model results were calibrated to California cost estimating standards through the use of "State Adjustment Factors" as provided in the USA Corps of Engineers Civil Works Construction Cost Index System (CWCCIS, USACE Engineer Manual EM 1110-2-1304), Table A-3. This manual is available at http://www.nww.usace.army.mil/cost. The current adjustment for California is 1.18 times the national estimate.

RETScreen^{TM} allows the analysis of six types of turbines: two axial flow types (Kaplan and Propeller), two impulse types (Pelton and Turgo), and Francis and Cross-flow type turbines. Other turbines types can be analyzed in the program, but most sites within the program's range of analysis will fit one of the provided types. The range of analysis for this study is limited to a flow of not less than one cubic feet per second and a maximum head of 30 meters (98.5 feet). RETScreen^{TM} has a range limit of 30 MW output for these study purposes. There is no limit for minimum flows.

The following assumptions were employed in estimating small hydropower potential and estimated capital costs for identified sites.

- Although the program allows consideration of multiple unit configurations at each site, only one unit was assumed at each location.
- Tailwater elevations were set at 0.1 meter above sea level to provide a consistent basis for evaluation. The majority of water purveyors in the State of California are at elevations low enough that atmospheric pressure variations are negligible.
- Water temperatures were set at 18 degrees C (average summer temperature for many California water purveyors).
- The percent head loss for intake runners was set at five as suggested in supporting documentation. While the head loss on intake runners will vary greatly depending on individual site constraints, 5% is a reasonable planning estimate.
- The generator power factor and efficiency was set at 0.95 (95%) for all units based on utility quality generators.
- Although somewhat higher in cost, custom designed utility quality turbines were assumed as they demonstrate higher efficiencies in the RETScreen^{TM} software.
- The operating hours were assumed at seventy percent run time during a six-month irrigation season (3066 hours). Most irrigation districts deliver over a six-month to seven-month period. Irrigators in the desert south may irrigate year around while irrigators in the northern portion of California may irrigate less than six months. No attempt was made to vary the run time based on individual sites or individual purveyors. (Note, however, that RETScreen^{TM} was used to compute installed capacity. As described in Section 2.5, estimated output was then computed separately for irrigation districts and municipal water systems. To the extent that seasonal hydrology was available, that was taken into account when computing seasonal and annual output. Therefore, this RETScreen^{TM} parameter had no impact on estimated output.)
- The value of generated power was assumed at $0.057 per kWh. This value is consistent with the then-current proxy for the "market price

referent" adopted by the California Public Utilities Commission for the average price of bulk power.

- Frost days were assumed at the minimum value available in the program.
- The type of development was assumed as "run of the river (canal in most cases)" with no more than part day storage.
- The cost factor was entered as 14 for the US at the time of program development per program instructions. A cost adjustment for screening purposes will be applied to the final analysis.
- Transmission line lengths were assumed at 0.1 kilometers. Since site-specific development factors were beyond the scope of this study, no attempt was made to account for individual site variances.
- Access road lengths were assumed the same as transmission line lengths. Again, no attempt was made to account for individual site variances.
- Access factor was assumed as fairly level ground, minimal access restrictions.
- Transmission line voltage was assumed at 12 kV

RETScreen™ calculates estimated (screening level) capital cost in millions of dollars and a pay back period in years based on the given power value. Efficiency curves and tables are calculated for the turbines that will fit each analysis including a best-fit recommendation. The output from these computations provided the estimated capacity and cost for each identified site based on "best fit" turbine option. RETScreen™ output was reviewed by engineers to confirm that the estimates were consistent with their professional judgment.

The RETscreen™ program determined that the most feasible technologies would be a "Saxo" Kaplan or a horizontal axis, angle inlet Kaplan, either one in the high 80% efficiency range.

A review of average efficiency curves for the various turbine types indicates that the Pelton and Kaplan turbines exhibit broader ranges of efficiencies than do the other general turbine types. The efficiencies exhibited by Kaplan turbines, depending on local installation details, range from 72 percent at 40 percent of flow capacity to almost 93 percent at 100 percent of flow capacity. Below 30 to 40 percent of flow, all turbine technologies lose efficiency rapidly as the percent of flow diminishes. While turbine technologies vary in their efficiencies, for purposes of this study it is assumed that generator efficiencies will be identical as they are independent of the driver (turbine) efficiency. Given the expected ranges of flow exhibited by irrigation systems and to some degree by municipal water systems, a broad range of higher efficiencies would be advantageous to allow as high a potential generation capacity as possible. Manipulation of the model by entering differing head and flow ranges verified this approach.

For purposes of this study, estimated efficiencies for general Kaplan style turbines were applied to opportunities with head ranging from 15' to 50'. Pelton style turbines were applied to limited, high head situations (i.e., more than 50').

The formulas used in the RETScreen™ calculations are provided in on-line "Clean Energy Project Analysis e-Textbook" found at the same internet address. Additional data and supporting documentation is provided in the conference proceedings publication "Turbine Selection for small low-head hydro developments" by J. L. Gordon, July 29, 2003. J.L. Gordon is one of the developers for the hydro portion of the RETScreen™ software.

E. Hydropower Equipment, Technologies and Costs

In addition to the "best fit" technology and cost output from RETScreen™, the following references were utilized to determine capital and operating costs for various types of equipment and project configurations.

- "Turbine selection for small low-head hydro developments", J. L. Gordon, P. Eng., Hydropower consultant; prepared for the pre-conference workshop "INNOVATIVE SMALL HYDRO TECHNOLOGIES" organized by Natural Resources Canada for WATERPOWER XIII; July 29, 2003, Buffalo, New York.

- "Using Benchmarking to Assess, Improve Hydro Plant Performance", James R. Schetter, Hydroreview October 2002.

In addition, the followed articles were utilized to describe opportunities for incremental hydropower in Section 3.6.

- "Hydropower Capacity Increase Opportunities", Douglas G. Hall, Idaho National Engineering and Environmental Laboratory (INEEL), U.S. Department of Energy Renewable Energy Modeling Series, May 10, 2005.

- "Best Practice Guidelines for the Hydro Performance Process and Implications for Incremental Hydropower," March, P. A., 2004 World Renewable Energy Conference, Denver, Colorado, September 2004.

- "Optimization-Based Hydro Performance Indicator," March, P. A., and P. J. Wolff, Proceedings of WaterPower XIII, July 2003.

F. Barriers and Hurdles to Development of In-Conduit Hydropower

The Energy Commission’s “2005 Integrated Energy Policy Report” (IEPR Docket 04-IEPR-01E, CEC-100-2005-007-CMF, November 2005, Chapter 8 – Integrating Water and Energy Strategies) and the supporting staff study, “California’s Water-Energy Relationship” (CEC-700-2005-011-SF, November 2005) contained substantive discussions about the barriers and hurdles to development of in-conduit hydropower that were summarized in Section 3.5.

II-List of Included Water Purveyors

Large to Small	Size	Type	Region	Name of Water Purveyor	County	Water Entitlements
1	L	I	C	Turlock I.D.	Stanislaus	3,936,017
2	L	I	S	Imperial I.D.	Imperial	3,265,995
3	L	M	S	Metropolitan Water District of Southern California	Los Angeles	2,156,500
4	L	I	N	Yolo County F.C.W.C.D.	Yolo	1,199,192
5	L	I	C	Westlands W.D.	Fresno	1,154,198
6	L	I	N	Glenn Colusa I.D.	Glenn	1,105,000
7	L	M	S	Los Angeles Department of Water and Power	Los Angeles	795,454
8	L	I	C	Merced I.D.	Merced	570,000
9	L	I	C	Central California I.D.	Merced	560,000
10	L	I	C	Fresno ID	Fresno	550,000
11	L	I	S	Coachella Valley W.D.	Riverside	508,100
12	L	I	S	Semitropic W.S.D.	Kern	500,000
13	M	M	N	Solano County WA	Solano	467,000
14	M	I	C	Kaweah Delta W.C.D.	Tulare	440,000
15	M	I	S	Palo Verde ID	Riverside	420,000
16	M	M	C	Inyo County Water Department	Inyo	400,000
17	M	I	S	Arvin-Edision W.S.D.	Kern	351,675
18	M	I	C	Madera-Chowchilla Water and PA	Madera	350,000
19	M	I	C	Modesto I.D.	Stanislaus	349,800
20	M	I	C	Lower Tule River I.D.	Tulare	330,302
21	M	I	C	Oakdale I.D.	Stanislaus	327,000
22	M	I	N	South San Joaquin I.D.	San Joaquin	300,000
23	M	I	N	Yuba County Water Agency	Yuba	300,000
24	M	I	C	Madera I.D.	Madera	295,000
25	M	M	N	San Francisco PUC	San Francisco	291,236
26	M	M	S	San Diego County Water Authority	San Diego	277,000
27	M	I	C	Kings County W.D.	Kings	256,938
28	M	M	C	Santa Clara Valley W.D.	Santa Clara	252,500
29	M	I	N	Reclamation District 108	Colusa	250,000
30	M	I	N	Tulelake Irrigation District	Modoc	250,000
31	M	I	C	Consolidated I.D.	Fresno	240,000
32	M	I	C	Chowchilla W.D.	Madera	239,000
33	M	M	S	City of San Diego	San Diego	235,245
34	M	I	N	Biggs-West Gridley W.D.	Butte	227,000
35	M	M	S	Orange County WD	Orange	225,000
36	M	I	S	North Kern W.S.D.	Kern	222,000
37	M	I	S	Kern Delta W.D.	Kern	220,000
38	M	I	S	Wheeler Ridge-Maricopa W.S.D	Kern	220,000
39	M	M	N	Contra Costa W.D.	Contra Costa	195,000
40	M	I	S	Buena Vista W.S.D.	Kern	185,000
41	M	I	C	Delano-Earlimart I.D.	Tulare	183,300
42	M	I	C	Grassland W.D.	Merced	180,000
43	M	I	C	Alta I.D.	Tulare	177,368
44	M	I	N	Sutter Extension W.D.	Sutter	176,000
45	M	I	C	Tulare I.D.	Tulare	171,000
46	M	I	N	Banta-Carbona I.D.	San Joaquin	168,413
47	M	I	N	Anderson-Cottonwood I.D.	Shasta	165,000
48	M	I	S	Belridge W.S.D.	Kern	163,000

Large to Small	Size	Type	Region	Name of Water Purveyor	County	Water Entitlements
49	M	M	S	West Basin Municipal W.D.	Los Angeles	160,000
50	M	I	N	Solano I.D.	Solano	151,953
51	M	I	S	Central and West Basin Water Replenishment Dist	Los Angeles	150,000
52	M	M	N	East Bay M.U.D.	Alameda	150,000
53	M	M	C	Monterey County FC & WCD	Monterey	150,000
54	M	M	N	South San Joaquin MUD	San Joaquin	147,000
55	M	I	S	Antelope Valley-East Kern W.A.	Los Angeles	141,000
56	M	I	S	Berrenda Mesa W.D.	Kern	140,000
57	M	M	S	Central Basin Municipal W.D.	Los Angeles	140,000
58	M	I	S	Lost Hills W.D.	Kern	140,000
59	M	I	N	Butte Water District	Butte	133,200
60	M	I	N	Placer Co Water Agency	Placer	130,000
61	M	I	N	Richvale I.D.	Butte	130,000
62	M	I	C	Dept. of Fish and Game	Fresno	128,920
63	M	I	C	San Luis W.D.	Merced	125,080
64	M	I	N	Nevada I.D.	Nevada	119,375
65	M	I	C	Tulare Lake Drainage District	Kings	118,500
66	M	I	N	Woodbridge I.D.	San Joaquin	116,700
67	M	I	N	South Sutter W.D.	Sutter	110,000
68	M	M	S	San Bernardino Valley M.W.D.	San Bernardino	102,600
69	M	I	N	Colusa Basin Drainage District	Yolo	100,000
70	M	M	S	Castaic Lake WA	Los Angeles	95,200
71	M	M	S	Calleguas Municipal Water District	Ventura	95,000
72	M	M	N	Contra Costa County WA	Contra Costa	95,000
73	M	I	N	Sutter Mutal Water Company	Sutter	95,000
74	M	I	C	Panoche W.D.	Fresno	94,000
75	M	M	N	City of Sacramento, Utilities Department	Sacramento	90,000
76	M	I	S	Shafter-Wasco I.D.	Kern	89,600
77	M	I	C	West Stanislaus I.D.	Stanislaus	85,000
78	M	I	N	Central San Joaquin W.C.D.	San Joaquin	80,000
79	M	M	S	Eastern MWD	Riverside	77,016
80	M	I	S	Mojave WA	San Bernardino	75,800
81	M	I	S	Cawelo W.D.	Kern	75,000
82	M	I	C	Corcoran I.D.	Kings	75,000
83	M	I	N	Princeton-Codora-Glenn I.D.	Colusa	75,000
84	M	I	N	Reclamation District # 999	Yolo	75,000
85	M	I	N	Stockton-East W.D.	San Joaquin	75,000
86	M	I	S	Rosedale-Rio Bravo W.S.D.	Kern	70,000
87	M	I	N	Reclamation District 1004	Colusa	69,000
88	M	M	N	Alameda County FC & WCD, Zone 7	Alameda	68,000
89	M	M	S	Coastal Municipal W.D.	Orange	65,000
90	M	I	N	Westside W.D.	Siskiyou	65,000
91	M	I	N	El Dorado I.D.	El Dorado	62,630
92	M	I	N	Colusa County W.D.	Colusa	62,200
93	M	M	C	City of Fresno	Fresno	60,000
94	M	M	N	Sacramento M.U.D.	Sacramento	60,000
95	M	I	C	James I.D.	Fresno	59,220
96	M	I	C	Lakeside Irrigation Water Dist	Kings	55,000
97	M	I	C	Lindmore I.D.	Tulare	55,000
98	M	I	C	Saucelito I.D.	Tulare	54,000
99	M	I	C	Dudley Ridge W.D.	Kings	53,370
100	M	I	N	Orland-Artois W.D.	Glenn	53,000

Large to Small	Size	Type	Region	Name of Water Purveyor	County	Water Entitlements
101	M	M	N	Humboldt Bay M.W.D.	Humboldt	52,000
102	M	M	S	City of San Bernardino Municipal Water Dept.	San Bernardino	51,217
103	M	M	S	Three Valleys MWD	Los Angeles	51,000
104	M	I	C	Kings River W.D.	Fresno	50,000
105	M	M	S	Western MWD	Riverside	50,000
106	S	M	S	City of Long Beach Water Department	Los Angeles	46,475
107	S	I	C	Porterville I.D.	Tulare	46,000
108	S	M	S	Central Coast Water Authority	Santa Barbara	45,486
109	S	I	N	Kanawha W.D.	Glenn	45,000
110	S	I	C	Patterson W.D.	Stanislaus	45,000
111	S	I	N	Reclamation District No.2068	Solano	45,000
112	S	M	N	San Juan Suburban Water District	Placer	45,000
113	S	I	N	The West Side I.D.	San Joaquin	45,000
114	S	I	C	Tranquillity I.D.	Fresno	43,857
115	S	I	C	San Benito Co. WC&FC Dist.	San Benito	43,800
116	S	M	N	Alameda County Water District	Alameda	42,000
117	S	M	N	Maine Prairie W.D.	Solano	42,000
118	S	I	N	Byron Bethany I.D.	Contra Costa	40,000
119	S	M	S	Kern-Tulare W.D.	Kern	40,000
120	S	M	S	Valley Center Muncipal W.D.	San Diego	40,000
121	S	I	C	Orange Cove I.D.	Fresno	39,200
122	S	I	S	Desert Water Agency	Riverside	38,100
123	S	I	S	Helix W.D.	San Diego	35,500
124	S	I	N	Maxwell I.D.	Colusa	35,000
125	S	M	N	Sonoma County Water Agency	Sonoma	35,000
126	S	M	N	City of Roseville W.D.	Placer	32,000
127	S	I	C	Pixley I.D.	Tulare	31,102
128	S	I	C	Exeter I.D.	Tulare	30,500
129	S	M	N	Calaveras Co. W.D.	Calaveras	30,000
130	S	M	S	Rancho California W.D.	Riverside	30,000
131	S	I	N	South Feather Water & Power Agency	Butte	30,000
132	S	I	C	Terra Bella I.D.	Tulare	29,000
133	S	M	S	San Gabriel Valley Municipal Water District	San Bernardino	28,800
134	S	M	S	Irvine Ranch W.D.	Orange	28,500
135	S	I	S	Cachuma Operation and Maintenance Board	Santa Barbara	27,800
136	S	I	C	Lindsay-Strathmore I.D.	Tulare	27,500
137	S	I	C	Broadview W.D.	Fresno	27,000
138	S	M	N	Napa Co. F.C.W.C.D.	Napa	26,500
139	S	M	S	City of Glendale Water Dept.	Los Angeles	26,132
140	S	M	S	Santa Barbara County Water Agency	Santa Barbara	25,714
141	S	I	S	Chino Basin Municipal Water District	San Bernardino	25,000
142	S	I	N	Provident I.D.	Glenn	25,000
143	S	M	S	San Luis Obispo County Flood Control Water Conservation District	San Luis Obispo	25,000
144	S	I	S	Tehachapi-Cummings County W.D.	Kern	25,000
145	S	M	C	City of Turlock W.S.A	Stanislaus	24,551
146	S	M	N	San Juan W.D.	Placer	24,200
147	S	I	N	Bella Vista W.D.	Shasta	24,000
148	S	M	S	Rainbow MWD	San Diego	24,000
149	S	M	N	Sacramento County Water Agency	Sacramento	24,000
150	S	M	C	City of Sunnyvale	Santa Clara	23,761

Large to Small	Size	Type	Region	Name of Water Purveyor	County	Water Entitlements
151	S	M	C	City of Corcoran W.S.A	Kings	23,700
152	S	I	N	Corning W.D.	Tehama	23,000
153	S	M	S	City of Pasadena W.S.A	Los Angeles	22,942
154	S	M	S	Pasadena-City Water Dept.	Los Angeles	22,942
155	S	I	S	Sweetwater Authority	San Diego	22,500
156	S	M	N	Natomas Central M.W.D	Sacramento	22,000
157	S	I	N	Browns Valley I.D.	Yuba	21,000
158	S	I	N	Plain View W.D.	San Joaquin	20,600
159	S	M	C	City of San Jose	Santa Clara	20,280
160	S	M	N	County of Colusa (Stony)	Colusa	20,040
161	S	I	C	Alpaugh I.D.	Tulare	20,000
162	S	I	S	Casitas M.W.D.	Ventura	20,000
163	S	M	S	Devils Den W.D.	Kern	20,000
164	S	I	N	Feather W.D.	Sutter	20,000
165	VS	M	N	Dunnigan W.D.	Yolo	19,000
166	VS	I	S	Goleta County W.D.	Santa Barbara	18,500
167	VS	M	N	Montague Water Conser. Dist.	Siskiyou	18,500
168	VS	I	S	Moulton-Niguel Water District	Orange	18,250
169	VS	M	S	Cucamonga County W.D.	San Bernardino	18,000
170	VS	M	N	City of Napa W.S.A	Napa	17,300
171	VS	M	S	Palmdale W.D.	Los Angeles	17,300
172	VS	I	S	San Gorgonio Pass Water Agency	Riverside	17,300
173	VS	M	S	City of Anaheim	Orange	17,185
174	VS	M	N	Citrus Heights Water District	Sacramento	17,000
175	VS	I	C	Patterson ID	Stanislaus	16,500
176	VS	M	S	City of Santa Maria	Santa Barbara	16,200
177	VS	I	C	Pacheco W.D.	Merced	16,080
178	VS	I	C	Ivanhoe I.D.	Tulare	15,600
179	VS	M	N	Clear Creek C.S.D	Shasta	15,300
180	VS	I	C	El Nido I.D.	Merced	15,000
181	VS	I	S	Padre Dam MWD	San Diego	14,910
182	VS	M	N	City of Pleasanton W.S.A	Alameda	14,620
183	VS	M	S	City of Redlands	San Bernardino	14,525
184	VS	I	C	La Branza Water District	Merced	14,500
185	VS	I	S	Vista Irrigation District	San Diego	14,500
186	VS	I	C	Del Puerto Water District	Stanislaus	14,210
187	VS	I	C	Gravelly Ford W.D.	Madera	14,000
188	VS	I	S	Otay WD	San Diego	14,000
189	VS	I	S	Pleasant Valley County W.D.	Ventura	14,000
190	VS	I	C	Riverdale I.D.	Fresno	14,000
191	VS	M	C	Gavilan Water Conservation District	Santa Clara	13,400
192	VS	I	S	Rag Gulch W.D.	Kern	13,300
193	VS	I	N	Camp Far West I.D.	Placer	13,000
194	VS	I	C	Empire-West Side Irrigation District	Kings	13,000
195	VS	M	S	Las Virgenes Municipal W.D.	Los Angeles	13,000
196	VS	M	N	Fair Oaks W.D.	Sacramento	12,998
197	VS	M	S	City of Santa Ana W.S.A	Orange	12,725
198	VS	M	S	Costa Real Municipal Water District	San Diego	12,500
199	VS	I	S	Walnut Valley W.D.	Los Angeles	12,500
200	VS	I	S	East Valley Water District	San Bernardino	12,403
201	VS	M	C	City of Santa Cruz Water Department	Santa Cruz	12,000
202	VS	M	S	Lake Hemet Municipal W.D.	Riverside	12,000

Large to Small	Size	Type	Region	Name of Water Purveyor	County	Water Entitlements
203	VS	M	S	City of Burbank W.S.A	Los Angeles	11,900
204	VS	I	N	Glide W.D.	Glenn	10,500
205	VS	I	S	Rowland Area County W.D.	Los Angeles	10,500
206	VS	M	S	Fallbrook P.U.D.	San Diego	10,400
207	VS	M	C	City of Coalinga	Fresno	10,000
208	VS	M	N	City of Tracy	San Joaquin	10,000
209	VS	M	S	East Orange CWD	Orange	10,000
210	VS	I	N	Reclamation District # 900	Yolo	10,000
211	VS	I	C	Stone Corral I.D.	Tulare	10,000
212	VS	M	S	Tri-Cities Municipal W.D.	Orange	10,000
213	VS	M	S	Yorba Linda Service Area	Orange	10,000
214	VS	M	N	City of West Sacramento W.S.A	Yolo	9,680
215	VS	M	N	City of Yuba City Sevice Area	Sutter	9,600
216	VS	M	N	North Marin Water District	Marin	9,000
217	VS	I	C	Atwell Island W.D.	Tulare	8,900
218	VS	I	S	San Marcos County Water District	San Diego	8,900
219	VS	M	N	City of Redding W.S.A	Shasta	8,855
220	VS	I	S	Camrosa Co. W.D.	Ventura	8,640
221	VS	M	S	City of Pomona	Los Angeles	8,542
222	VS	M	C	City of Santa Clara	Santa Clara	8,516
223	VS	M	S	Foothill Municipal Water District	Los Angeles	8,500
224	VS	I	S	Santa Fe Irrigation District	San Diego	8,500
225	VS	M	S	North of the River M.W.D.	Kern	7,500
226	VS	M	S	San Dieguito W.D.	San Diego	7,500
227	VS	I	C	Tea Pot Dome W.D.	Tulare	7,500
228	VS	M	S	Ramona Municipal W.D.	San Diego	7,440
229	VS	M	S	Bueno Colorado Municipal Water District	San Diego	7,000
230	VS	M	S	Los Alisos Water District	Orange	7,000
231	VS	I	N	North San Joaquin W.C.D.	San Joaquin	7,000
232	VS	M	S	Olivenhain Municipal W.D.	San Diego	7,000
233	VS	M	S	City of Inglewood	Los Angeles	6,500
234	VS	M	N	Georgetown Divide P.U.D.	El Dorado	6,500
235	VS	I	C	Pajaro Valley W.M.A.	Santa Cruz	6,260
236	VS	I	N	Paradise Irrigation District	Butte	6,159
237	VS	I	S	West San Bernardino County W.D.	San Bernardino	6,080
238	VS	M	N	Belmont County Water District	San Mateo	6,000
239	VS	M	S	Crestline-Lake Arrowhead W.A.	San Bernardino	5,800
240	VS	M	S	Vandenberg Air Force Base	Santa Barbara	5,500
241	VS	I	C	Tulare County Water Works	Tulare	5,308
242	VS	M	S	Santa Margarita WD	Orange	5,012
243	VS	I	N	La Grande W.D.	Sonoma	5,000
244	VS	M	S	Rincon del Diablo MWD	San Diego	5,000
245	VS	I	N	Shasta County Water Agency	Shasta	5,000
246	VS	M	S	City of Newport Beach W.S.A	Orange	4,905
247	VS	M	S	City of Compton W.S.A	Orange	4,000
248	VS	M	S	Vernon Water Dept.	Los Angeles	3,637
249	VS	M	S	City of Alhambra W.S.A	Los Angeles	3,200
250	VS	I	S	Monte Vista Water District	San Bernardino	900

Key:

Characteristic	Key	Description
Size	L	Large (>=500 kAF)
	M	Medium (50 kAF – 499.9 kAF)
	S	Small (20 kAF – 49.9 kAF)
	VS	Very Small (5 kAF – 19.9 kAF)
Type	I	Irrigation
	M	Municipal
Region	N	North
	C	Central
	S	South

kAF = thousands of acre feet

III-List of Potential Sites Identified

(by Type and Region)

Site#	Type	Region	K W	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1	I	N	3,078	0	0	0	1,539	3,078	3,078	3,078	3,078	3,078	1,539	0	0
2	I	N	269	0	0	0	135	269	269	269	269	269	135	0	0
3	I	C	542	0	0	0	271	542	542	542	542	542	271	0	0
4	I	C	554	0	0	0	277	554	554	554	554	554	277	0	0
5	I	C	623	0	0	0	312	623	623	623	623	623	312	0	0
6	I	C	179	0	0	0	90	179	179	179	179	179	90	0	0
7	I	C	177	0	0	0	89	177	177	177	177	177	89	0	0
8	I	C	492	0	0	0	246	492	492	492	492	492	246	0	0
9	I	C	1,500	0	0	0	750	1,500	1,500	1,500	1,500	1,500	750	0	0
10	I	C	4,274	0	0	0	0	0	0	4,274	4,274	4,274	0	0	0
11	I	C	3,364	3,364	3,364	3,364	0	0	0	0	0	0	0	3,364	3,364
12	I	C	279	0	0	0	140	279	279	279	279	279	140	0	0
13	I	C	680	0	0	0	340	680	680	680	680	680	340	0	0
14	I	C	1,003	0	0	0	502	1,003	1,003	1,003	1,003	1,003	502	0	0
15	M	S	4,867	2,434	4,867	4,867	4,867	4,867	4,867	4,867	4,867	4,867	4,867	4,867	2,434
16	M	S	3,509	1,755	3,509	3,509	3,509	3,509	3,509	3,509	3,509	3,509	3,509	3,509	1,755
17	M	S	3,041	1,521	3,041	3,041	3,041	3,041	3,041	3,041	3,041	3,041	3,041	3,041	1,521
18	M	S	1,754	877	1,754	1,754	1,754	1,754	1,754	1,754	1,754	1,754	1,754	1,754	877
19	M	S	2,693	1,347	2,693	2,693	2,693	2,693	2,693	2,693	2,693	2,693	2,693	2,693	1,347
20	M	S	1,056	528	1,056	1,056	1,056	1,056	1,056	1,056	1,056	1,056	1,056	1,056	528
21	M	S	1,350	675	1,350	1,350	1,350	1,350	1,350	1,350	1,350	1,350	1,350	1,350	675
22	M	S	985	493	985	985	985	985	985	985	985	985	985	985	493
23	M	S	1,562	781	1,562	1,562	1,562	1,562	1,562	1,562	1,562	1,562	1,562	1,562	781
24	M	S	1,507	754	1,507	1,507	1,507	1,507	1,507	1,507	1,507	1,507	1,507	1,507	754
25	M	S	1,830	915	1,830	1,830	1,830	1,830	1,830	1,830	1,830	1,830	1,830	1,830	915
26	M	S	1,547	774	1,547	1,547	1,547	1,547	1,547	1,547	1,547	1,547	1,547	1,547	774
27	M	S	2,065	1,033	2,065	2,065	2,065	2,065	2,065	2,065	2,065	2,065	2,065	2,065	1,033
28	M	S	6,008	3,004	6,008	6,008	6,008	6,008	6,008	6,008	6,008	6,008	6,008	6,008	3,004
29	M	S	902	451	902	902	902	902	902	902	902	902	902	902	451
30	M	S	840	420	840	840	840	840	840	840	840	840	840	840	420
31	M	S	785	393	785	785	785	785	785	785	785	785	785	785	393
32	M	S	769	385	769	769	769	769	769	769	769	769	769	769	385
33	M	S	764	382	764	764	764	764	764	764	764	764	764	764	382
34	M	S	743	372	743	743	743	743	743	743	743	743	743	743	372
35	M	S	711	356	711	711	711	711	711	711	711	711	711	711	356
36	M	S	673	337	673	673	673	673	673	673	673	673	673	673	337
37	M	S	3,366	1,683	3,366	3,366	3,366	3,366	3,366	3,366	3,366	3,366	3,366	3,366	1,683
38	M	S	1,924	962	1,924	1,924	1,924	1,924	1,924	1,924	1,924	1,924	1,924	1,924	962
39	M	S	423	212	423	423	423	423	423	423	423	423	423	423	212
40	M	S	337	169	337	337	337	337	337	337	337	337	337	337	169
41	M	S	462	231	462	462	462	462	462	462	462	462	462	462	231
42	M	S	646	323	646	646	646	646	646	646	646	646	646	646	323
43	M	S	289	145	289	289	289	289	289	289	289	289	289	289	145
44	M	S	1,508	754	1,508	1,508	1,508	1,508	1,508	1,508	1,508	1,508	1,508	1,508	754
45	M	S	700	350	700	700	700	700	700	700	700	700	700	700	350
46	M	S	300	150	300	300	300	300	300	300	300	300	300	300	150
47	M	S	2,308	1,154	2,308	2,308	2,308	2,308	2,308	2,308	2,308	2,308	2,308	2,308	1,154
48	I	S	473	237	473	473	473	473	473	473	473	473	473	473	237
49	I	S	1,163	582	1,163	1,163	1,163	1,163	1,163	1,163	1,163	1,163	1,163	1,163	582
50	I	S	1,209	605	1,209	1,209	1,209	1,209	1,209	1,209	1,209	1,209	1,209	1,209	605
51	I	S	552	276	552	552	552	552	552	552	552	552	552	552	276
52	I	S	439	220	439	439	439	439	439	439	439	439	439	439	220
53	I	S	338	169	338	338	338	338	338	338	338	338	338	338	169
54	I	S	174	87	174	174	174	174	174	174	174	174	174	174	87
55	I	S	582	291	582	582	582	582	582	582	582	582	582	582	291
56	I	S	655	328	655	655	655	655	655	655	655	655	655	655	328
57	I	S	209	105	209	209	209	209	209	209	209	209	209	209	105
58	I	S	269	135	269	269	269	269	269	269	269	269	269	269	135

Site#	Type	Region	K W	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
59	I	S	148	74	148	148	148	148	148	148	148	148	148	148	74
60	I	S	459	230	459	459	459	459	459	459	459	459	459	459	230
61	I	S	476	238	476	476	476	476	476	476	476	476	476	476	238
62	I	S	175	88	175	175	175	175	175	175	175	175	175	175	88
63	I	S	558	279	558	558	558	558	558	558	558	558	558	558	279
64	I	S	649	325	649	649	649	649	649	649	649	649	649	649	325
65	I	S	149	75	149	149	149	149	149	149	149	149	149	149	75
66	I	S	156	78	156	156	156	156	156	156	156	156	156	156	78
67	I	S	353	177	353	353	353	353	353	353	353	353	353	353	177
68	I	S	353	177	353	353	353	353	353	353	353	353	353	353	177
69	I	S	404	0	0	0	202	404	404	404	404	404	202	0	0
70	I	S	404	0	0	0	202	404	404	404	404	404	202	0	0
71	I	S	404	0	0	0	202	404	404	404	404	404	202	0	0
72	I	S	404	0	0	0	202	404	404	404	404	404	202	0	0
73	I	S	346	0	0	0	0	0	0	346	346	0	0	0	0
74	I	S	346	0	0	0	0	0	0	346	346	0	0	0	0
75	I	S	308	0	0	0	154	308	308	308	308	308	154	0	0
76	I	C	1,108	0	0	0	554	1,108	1,108	1,108	1,108	1,108	554	0	0
77	I	C	1,616	0	0	0	808	1,616	1,616	1,616	1,616	1,616	808	0	0
78	I	C	2,239	0	0	0	1,120	2,239	2,239	2,239	2,239	2,239	1,120	0	0
79	I	C	212	0	0	0	106	212	212	212	212	212	106	0	0
80	I	C	212	0	0	0	106	212	212	212	212	212	106	0	0
81	I	C	154	0	0	0	77	154	154	154	154	154	77	0	0
82	I	N	135	0	0	0	0	0	0	135	135	0	0	0	0
83	I	N	225	0	0	0	0	0	0	225	225	0	0	0	0
84	I	N	289	0	0	0	145	289	289	289	289	289	145	0	0
85	I	N	1,231	0	0	0	1,231	1,231	1,231	1,231	1,231	1,231	1,231	0	0
86	I	N	1,731	866	866	866	1,731	1,731	1,731	1,731	1,731	1,731	866	866	866
87	I	N	406	203	406	406	406	406	406	406	406	406	406	406	203
88	I	N	609	305	609	609	609	609	609	609	609	609	609	609	305
89	I	N	215	0	0	0	0	0	215	215	215	215	0	0	0
90	I	N	365	0	0	0	183	365	365	365	365	365	183	0	0
91	I	N	1,308	0	0	0	0	1,308	1,308	1,308	1,308	1,308	1,308	0	0
92	I	S	7,174	0	0	0	0	7,174	7,174	7,174	7,174	0	0	0	0
93	I	S	566	283	566	566	566	566	566	566	566	566	566	566	283
94	I	S	1,539	0	0	0	0	0	1,539	1,539	1,539	0	0	0	0
95	I	S	1,539	0	0	0	0	0	1,539	1,539	1,539	0	0	0	0
96	I	S	262	0	0	0	0	0	262	262	262	0	0	0	0
97	I	S	962	0	0	0	0	0	962	962	962	0	0	0	0
98	I	S	231	0	0	0	0	0	231	231	231	0	0	0	0
99	I	S	269	0	0	0	0	0	269	269	269	0	0	0	0
100	I	S	131	0	0	0	0	0	131	131	131	0	0	0	0
101	I	S	3,078	0	0	0	0	0	3,078	3,078	3,078	0	0	0	0
102	I	S	462	0	0	0	462	462	462	462	462	462	462	0	0
103	I	S	462	0	0	0	462	462	462	462	462	462	462	0	0
104	I	S	2,462	1,231	2,462	2,462	2,462	2,462	2,462	2,462	2,462	2,462	2,462	2,462	1,231
105	M	C	481	0	0	0	0	481	481	481	481	481	481	0	0
106	M	C	104	0	0	0	0	104	104	104	104	104	104	0	0
107	M	C	616	0	0	0	0	616	616	616	616	616	616	0	0
108	M	C	519	0	0	0	0	519	519	519	519	519	519	0	0
109	M	N	1,440	720	1,440	1,440	1,440	1,440	1,440	1,440	1,440	1,440	1,440	1,440	720
110	M	N	667	334	667	667	667	667	667	667	667	667	667	667	334
111	M	N	1,200	600	1,200	1,200	1,200	1,200	1,200	1,200	1,200	1,200	1,200	1,200	600
112	M	N	2,000	1,000	2,000	2,000	2,000	2,000	2,000	2,000	2,000	2,000	2,000	2,000	1,000
113	M	N	151	0	0	0	0	0	151	151	151	151	151	0	0
114	M	N	1,558	0	0	0	0	0	0	1,558	1,558	1,558	1,558	0	0
115	M	N	277	0	0	0	277	277	277	277	0	0	0	0	0
116	M	N	9,806	4,903	9,806	9,806	9,806	9,806	9,806	9,806	9,806	9,806	9,806	9,806	4,903
117	M	N	866	433	866	866	866	866	866	866	866	866	866	866	433
118	M	N	953	477	953	953	953	953	953	953	953	953	953	953	477
119	M	S	100	50	100	100	100	100	100	100	100	100	100	100	50
120	M	S	254	0	0	0	0	0	254	254	254	0	0	0	0
121	M	S	108	54	108	108	108	108	108	108	108	108	108	108	54
122	M	S	108	54	108	108	108	108	108	108	108	108	108	108	54
123	M	S	1,335	1,335	1,335	1,335	1,335	0	0	0	0	1,335	1,335	1,335	1,335

Site#	Type	Region	K W	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
124	M	S	4,240	4,240	4,240	4,240	4,240	0	0	0	0	4,240	4,240	4,240	4,240
125	M	S	1,822	1,822	1,822	1,822	1,822	0	0	0	0	1,822	1,822	1,822	1,822
126	M	S	1,513	1,513	1,513	1,513	1,513	1,513	1,513	1,513	1,513	1,513	1,513	1,513	1,513
127	M	S	231	0	0	0	0	231	231	231	231	231	231	0	0
128	M	S	154	0	0	0	0	154	154	154	154	154	154	0	0

Key:

Characteristic	Key	Description
Size	L	Large (>=500 kAF)
	M	Medium (50 kAF – 499.9 kAF)
	S	Small (20 kAF – 49.9 kAF)
Type	I	Irrigation
	M	Municipal
Region	N	North
	C	Central
	S	South

kAF = thousands of acre feet

IV-Surveyed Counties in Relation to "Hot Spots"

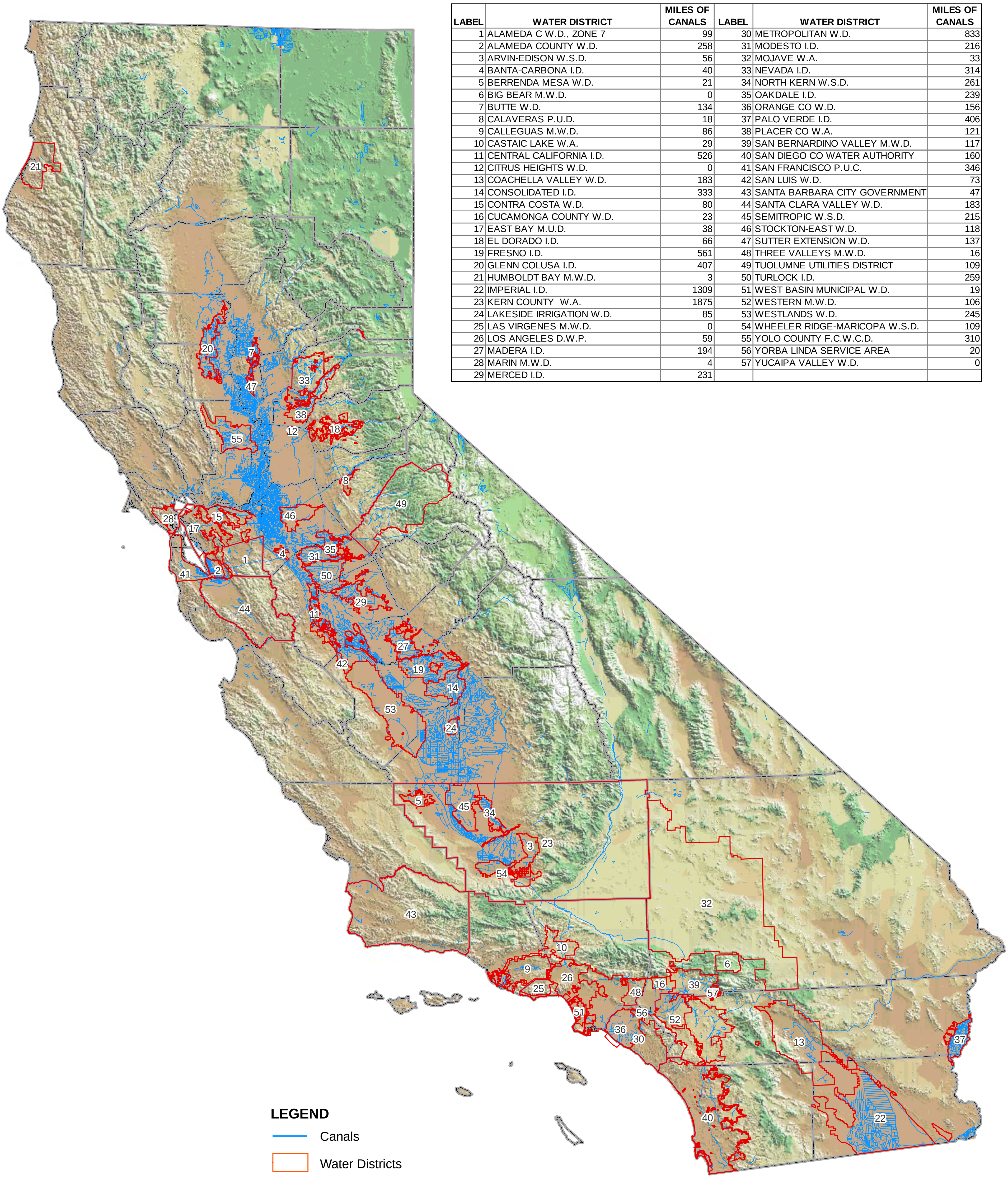
County	# of "Hot Spots"		% Area Surveyed	Total Acres
	2010	2017		
ALAMEDA	63	98	99%	524,750
ALPINE			0%	474,105
AMADOR		17	0%	387,429
BUTTE	67	70	2%	1,073,166
CALAVERAS		14	3%	663,008
COLUSA			14%	739,950
CONTRA COSTA	5	93	52%	514,952
DEL NORTE			0%	650,075
EL DORADO	8	35	12%	1,145,527
FRESNO	1	149	26%	3,851,269
GLENN			9%	849,231
HUMBOLDT		1	9%	2,293,597
IMPERIAL	17		38%	2,868,546
INYO			0%	6,547,396
KERN	32	181	100%	5,223,347
KINGS		23	13%	890,657
LAKE		2	0%	851,669
LASSEN	2	2	0%	3,019,663
LOS ANGELES	78	38	60%	2,615,386
MADERA		37	9%	1,378,185
MARIN	17	29	25%	378,976
MARIPOSA		8	0%	934,972
MENDOCINO			0%	2,248,700
MERCED	5	45	25%	1,261,122
MODOC			0%	2,690,177
MONO			0%	2,004,931
MONTEREY	7	70	0%	2,120,221
NAPA	2	21	0%	505,822
NEVADA	11	12	33%	623,184
ORANGE	29	12	100%	511,492
PLACER	35	55	21%	960,110
PLUMAS	28	28	0%	1,673,585
RIVERSIDE	66	2	35%	4,672,365
SACRAMENTO	7	70	1%	635,854
SAN BENITO	1	8	0%	889,415
SAN BERNARDINO	38	5	28%	12,867,265
SAN DIEGO	218	212	71%	2,712,306
SAN FRANCISCO	20	20	38%	68,788
SAN JOAQUIN	48	92	16%	911,727
SAN LUIS OBISPO	3	39	0%	2,124,832

County	# of "Hot Spots"		% Area Surveyed	Total Acres
	2010	2017		
SAN MATEO	56	58	39%	353,366
SANTA BARBARA	2	28	93%	1,759,234
SANTA CLARA	73	109	100%	835,905
SANTA CRUZ	1	18	1%	285,635
SHASTA	3	31	0%	2,462,044
SIERRA	4	4	0%	615,675
SISKIYOU			0%	4,065,126
SOLANO	6	20	0%	582,146
SONOMA	2	37	0%	1,025,354
STANISLAUS	3	80	34%	969,630
SUTTER	33	34	11%	389,470
TEHAMA			0%	1,894,878
TRINITY			0%	2,053,368
TULARE	1	7	0%	3,098,361
TUOLUMNE	3	44	58%	1,457,683
VENTURA	6	6	41%	1,188,282
YOLO	18	19	32%	653,897
YUBA	29	29	0%	412,097
TOTALS	1048	2012		

V-Project Maps

MILES OF CANALS PER SELECTED WATER DISTRICT

LABEL	WATER DISTRICT	MILES OF CANALS	LABEL	WATER DISTRICT	MILES OF CANALS
1	ALAMEDA C W.D., ZONE 7	99	30	METROPOLITAN W.D.	833
2	ALAMEDA COUNTY W.D.	258	31	MODESTO I.D.	216
3	ARVIN-EDISON W.S.D.	56	32	MOJAVE W.A.	33
4	BANTA-CARBONA I.D.	40	33	NEVADA I.D.	314
5	BERRENDA MESA W.D.	21	34	NORTH KERN W.S.D.	261
6	BIG BEAR M.W.D.	0	35	OAKDALE I.D.	239
7	BUTTE W.D.	134	36	ORANGE CO W.D.	156
8	CALAVERAS P.U.D.	18	37	PALO VERDE I.D.	406
9	CALLEGUAS M.W.D.	86	38	PLACER CO W.A.	121
10	CASTAIC LAKE W.A.	29	39	SAN BERNARDINO VALLEY M.W.D.	117
11	CENTRAL CALIFORNIA I.D.	526	40	SAN DIEGO CO WATER AUTHORITY	160
12	CITRUS HEIGHTS W.D.	0	41	SAN FRANCISCO P.U.C.	346
13	COACHELLA VALLEY W.D.	183	42	SAN LUIS W.D.	73
14	CONSOLIDATED I.D.	333	43	SANTA BARBARA CITY GOVERNMENT	47
15	CONTRA COSTA W.D.	80	44	SANTA CLARA VALLEY W.D.	183
16	CUCAMONGA COUNTY W.D.	23	45	SEMITROPIC W.S.D.	215
17	EAST BAY M.U.D.	38	46	STOCKTON-EAST W.D.	118
18	EL DORADO I.D.	66	47	SUTTER EXTENSION W.D.	137
19	FRESNO I.D.	561	48	THREE VALLEYS M.W.D.	16
20	GLENN COLUSA I.D.	407	49	TUOLUMNE UTILITIES DISTRICT	109
21	HUMBOLDT BAY M.W.D.	3	50	TURLOCK I.D.	259
22	IMPERIAL I.D.	1309	51	WEST BASIN MUNICIPAL W.D.	19
23	KERN COUNTY W.A.	1875	52	WESTERN M.W.D.	106
24	LAKESIDE IRRIGATION W.D.	85	53	WESTLANDS W.D.	245
25	LAS VIRGENES M.W.D.	0	54	WHEELER RIDGE-MARICOPA W.S.D.	109
26	LOS ANGELES D.W.P.	59	55	YOLO COUNTY F.C.W.C.D.	310
27	MADERA I.D.	194	56	YORBA LINDA SERVICE AREA	20
28	MARIN M.W.D.	4	57	YUCAIPA VALLEY W.D.	0
29	MERCED I.D.	231			



LEGEND

- Canals
- Water Districts
- Counties

0 25 50 100 Miles

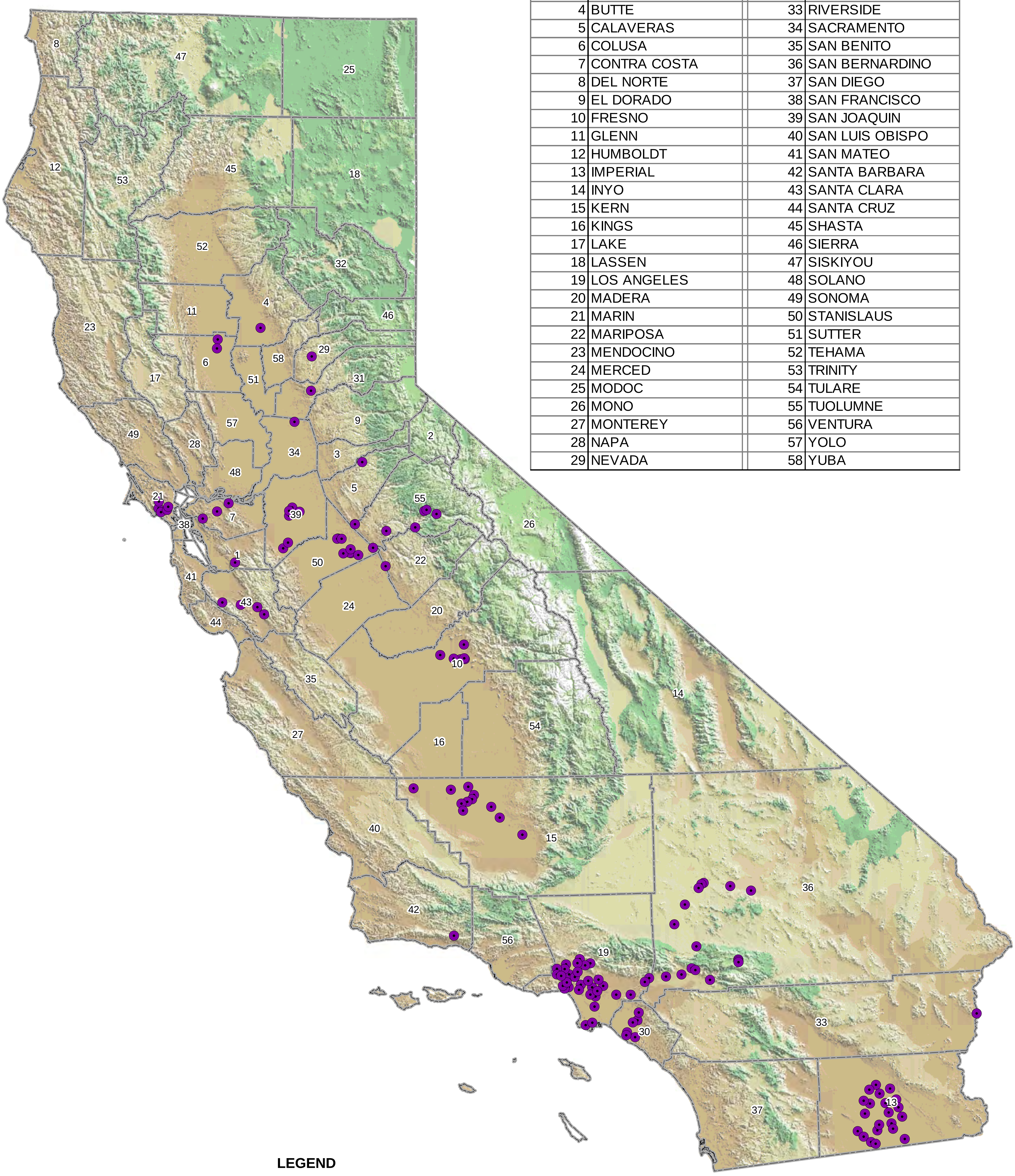
SOURCE: California Spatial Library.

DISCLAIMER - Every reasonable effort has been made to assure the accuracy of maps and data. Nevertheless, some information may not be 100% accurate.

CEC PIER Statewide Small Hydropower Assessment, California	Bookman-Edmonston A Division of GEI Consultants	WATER DISTRICTS AND CANALS
California Energy Commission		AUGUST 2004 FIGURE 1

08-25-04 S:/GIS/Projects/040280/FINAL_DATA/WDandCanals.mxd

LABEL	COUNTY	LABEL	COUNTY
1	ALAMEDA	30	ORANGE
2	ALPINE	31	PLACER
3	AMADOR	32	PLUMAS
4	BUTTE	33	RIVERSIDE
5	CALAVERAS	34	SACRAMENTO
6	COLUSA	35	SAN BENITO
7	CONTRA COSTA	36	SAN BERNARDINO
8	DEL NORTE	37	SAN DIEGO
9	EL DORADO	38	SAN FRANCISCO
10	FRESNO	39	SAN JOAQUIN
11	GLENN	40	SAN LUIS OBISPO
12	HUMBOLDT	41	SAN MATEO
13	IMPERIAL	42	SANTA BARBARA
14	INYO	43	SANTA CLARA
15	KERN	44	SANTA CRUZ
16	KINGS	45	SHASTA
17	LAKE	46	SIERRA
18	LASSEN	47	SISKIYOU
19	LOS ANGELES	48	SOLANO
20	MADERA	49	SONOMA
21	MARIN	50	STANISLAUS
22	MARIPOSA	51	SUTTER
23	MENDOCINO	52	TEHAMA
24	MERCED	53	TRINITY
25	MODOC	54	TULARE
26	MONO	55	TUOLUMNE
27	MONTEREY	56	VENTURA
28	NAPA	57	YOLO
29	NEVADA	58	YUBA



LEGEND

Potential Sites

Counties

0 25 50 100 Miles

SOURCE: California Spatial Library.

DISCLAIMER - Every reasonable effort has been made to assure the accuracy of maps and data. Nevertheless, some information may not be 100% accurate.

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California Energy Commission

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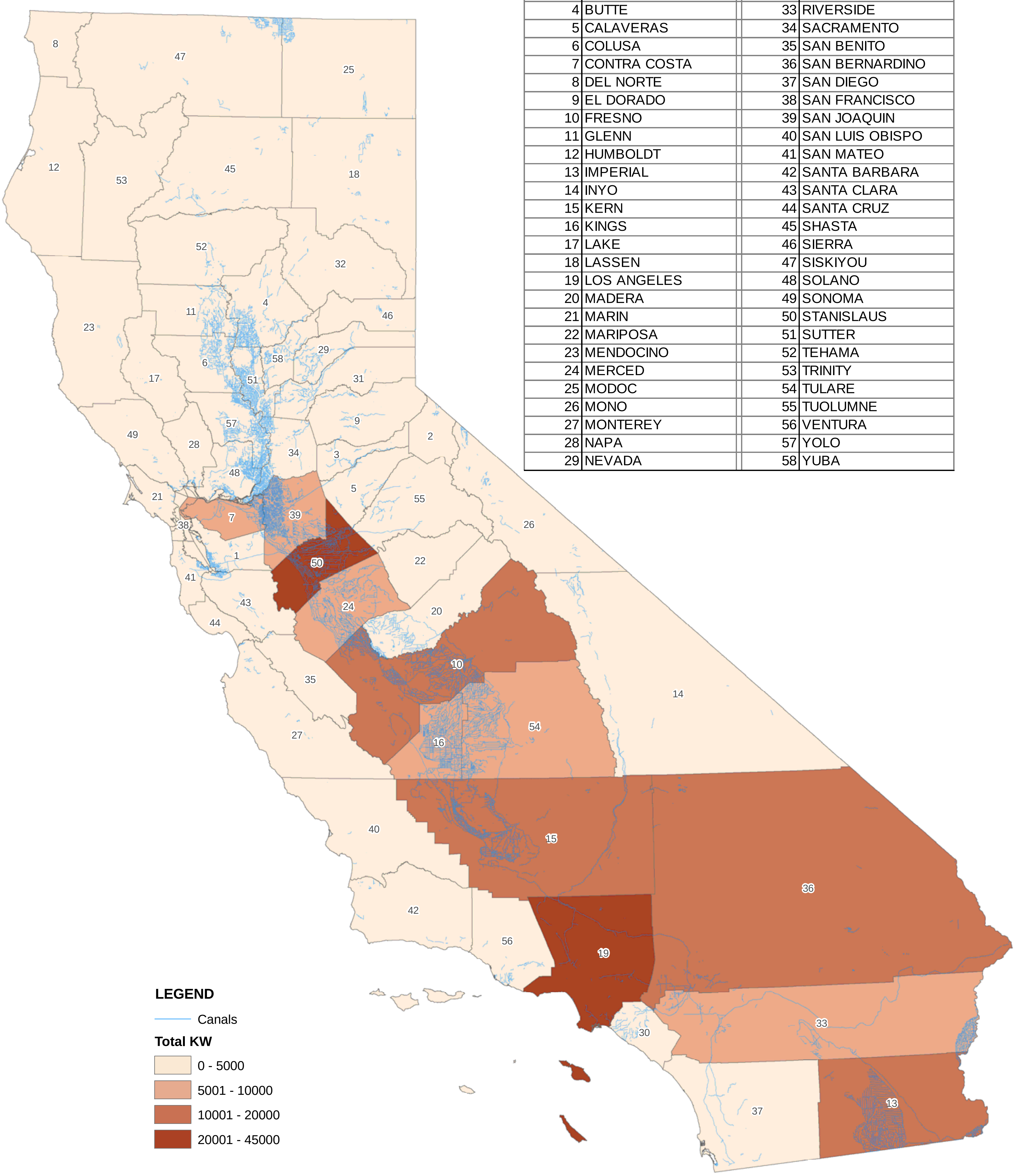
POTENTIAL SMALL HYDROPOWER SITES

AUGUST 2004

FIGURE 2

08-25-04 S:/GIS/Projects/040280/FINAL_DATA/PotentialSites.mxd

LABEL	COUNTY	LABEL	COUNTY
1	ALAMEDA	30	ORANGE
2	ALPINE	31	PLACER
3	AMADOR	32	PLUMAS
4	BUTTE	33	RIVERSIDE
5	CALAVERAS	34	SACRAMENTO
6	COLUSA	35	SAN BENITO
7	CONTRA COSTA	36	SAN BERNARDINO
8	DEL NORTE	37	SAN DIEGO
9	EL DORADO	38	SAN FRANCISCO
10	FRESNO	39	SAN JOAQUIN
11	GLENN	40	SAN LUIS OBISPO
12	HUMBOLDT	41	SAN MATEO
13	IMPERIAL	42	SANTA BARBARA
14	INYO	43	SANTA CLARA
15	KERN	44	SANTA CRUZ
16	KINGS	45	SHASTA
17	LAKE	46	SIERRA
18	LASSEN	47	SISKIYOU
19	LOS ANGELES	48	SOLANO
20	MADERA	49	SONOMA
21	MARIN	50	STANISLAUS
22	MARIPOSA	51	SUTTER
23	MENDOCINO	52	TEHAMA
24	MERCED	53	TRINITY
25	MODOC	54	TULARE
26	MONO	55	TUOLUMNE
27	MONTEREY	56	VENTURA
28	NAPA	57	YOLO
29	NEVADA	58	YUBA



SOURCE: California Spatial Library.

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SMALL HYDROPOWER POTENTIAL BY COUNTY

AUGUST 2004

FIGURE 3

08-25-04 S:/GIS/Projects/040280/FINAL_DATA/PotentialbyCounty.mxd